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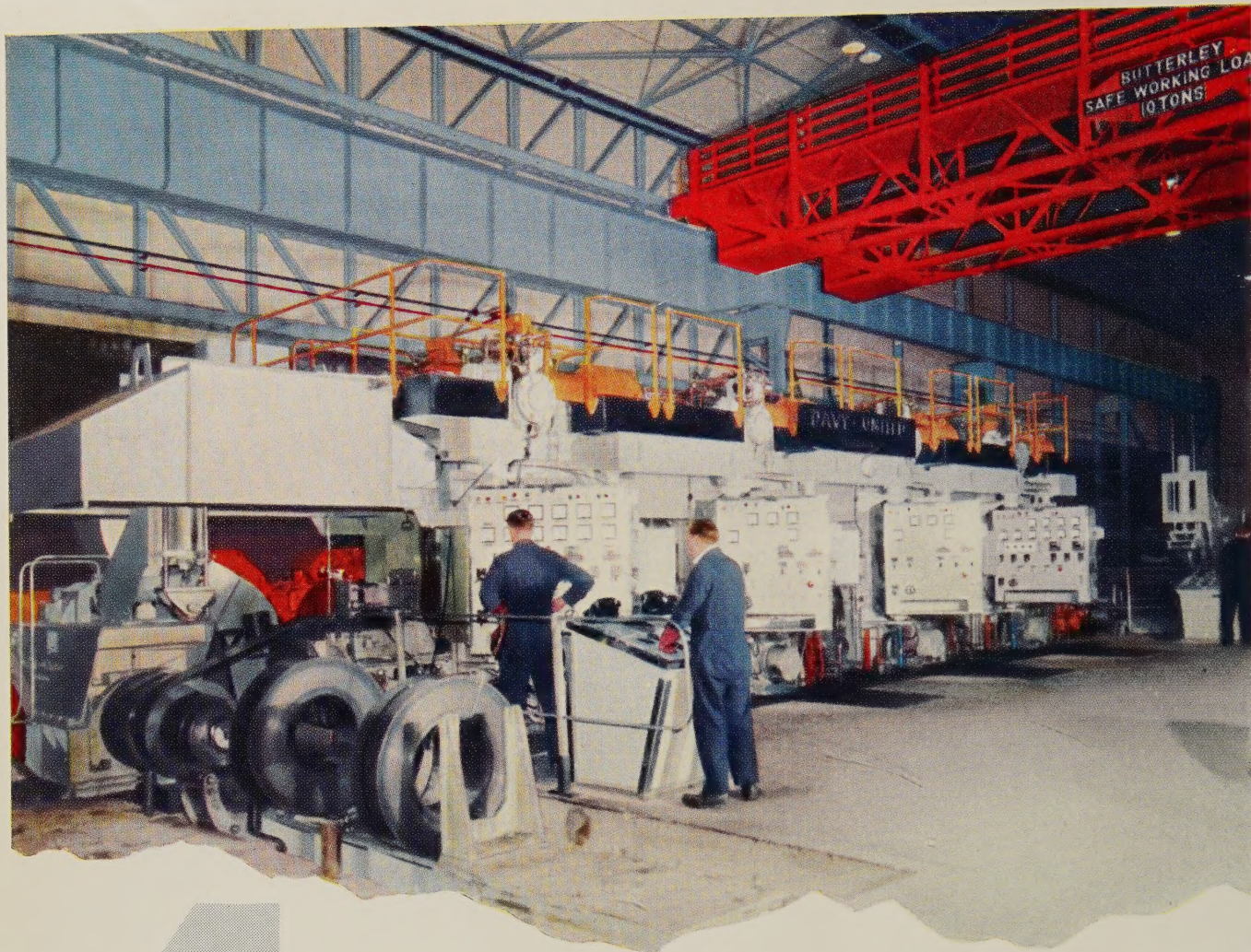


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JOURNAL OF THE IRON AND STEEL INSTITUTE

PRICE TWENTY-FIVE SHILLINGS



4

STAND

TANDEM COLD STRIP MILL

This new Davy-United $10\frac{1}{2}$ " and 26" x 22" 4-high 4-stand tandem cold strip mill rolls mild steel and high carbon strip from 4" to 18" wide at speeds up to 2,100 ft. per minute. The mill was installed in the Brinsworth plant of Steel, Peech & Tozer Branch of The United Steel Companies Limited.

Special Davy-United instrumentation on the mill consists of automatic gauge control on stands 1 and 4, loadmeters on all stands and automatic inter-stand tension control between stands 3 and 4.

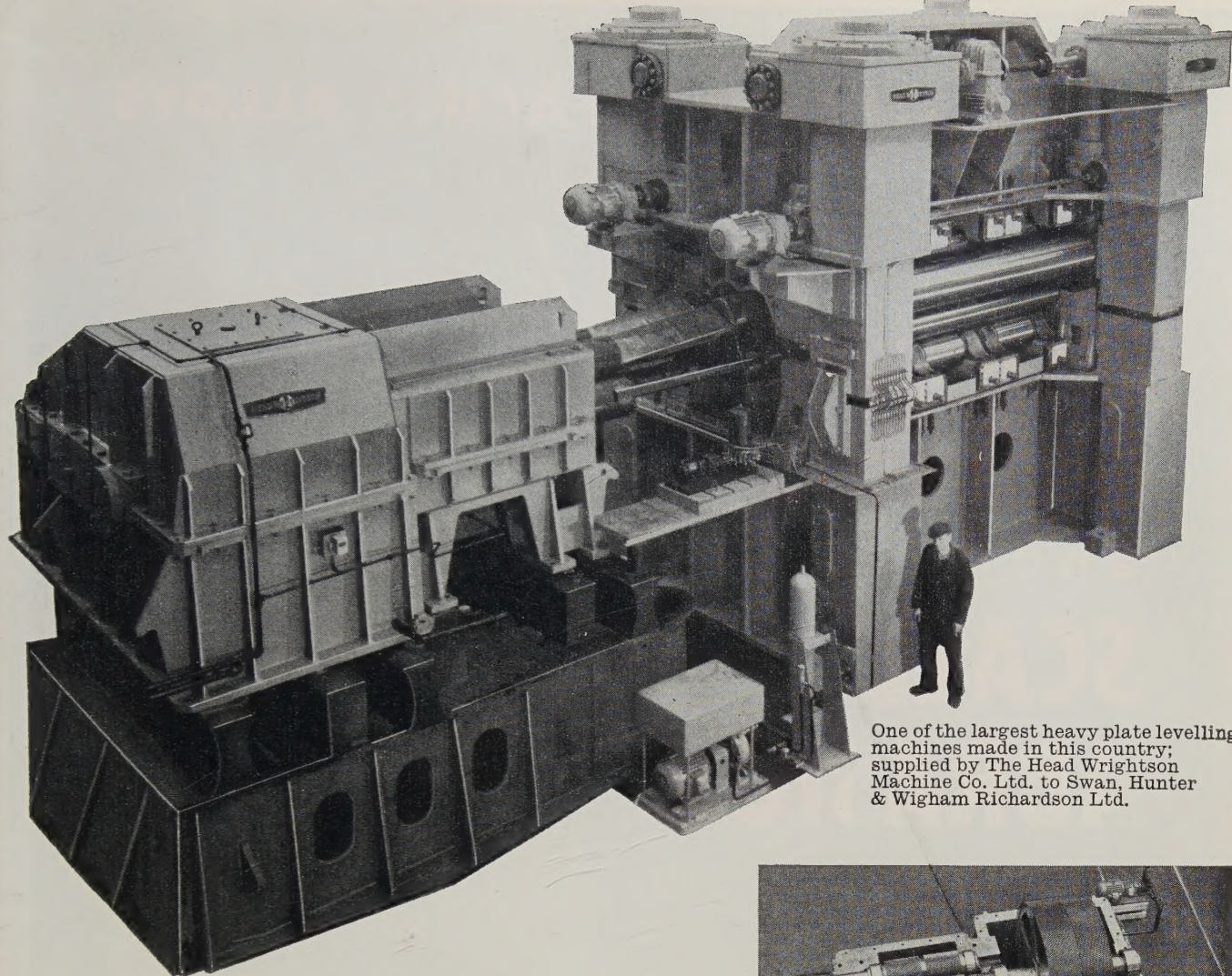
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DAVY AND UNITED ENGINEERING COMPANY LIMITED · SHEFFIELD
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Inside front cover

JOURNAL OF THE IRON AND STEEL INSTITUTE



One of the largest heavy plate levelling machines made in this country; supplied by The Head Wrightson Machine Co. Ltd. to Swan, Hunter & Wigham Richardson Ltd.

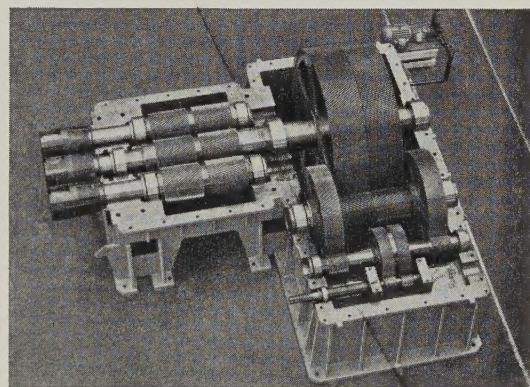
SKF

ball and roller bearings for this large plate levelling machine

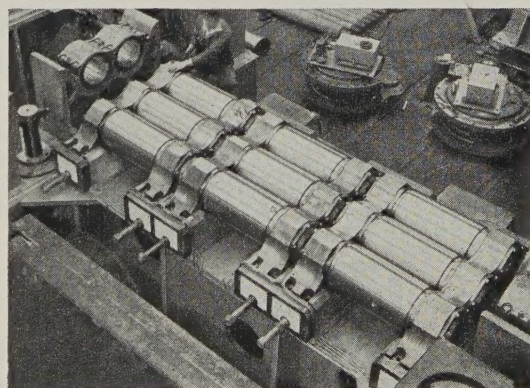
Designed to handle ships' plates up to 2 in. thick and 12 ft. wide, this plate leveller is equipped throughout with SKF ball and roller bearings. Spherical roller bearings are used for the backing rolls and screw-down worm gear, and spherical roller thrust bearings—each carrying over 800 tons, for the screw-down shafts.

Entry and exit tables incorporate 112 standard SKF plummer blocks.

For efficiency and trouble-free operation, this heavy-duty installation depends to a large extent on the reliability of SKF ball and roller bearings.



Triple-reduction gear box equipped with SKF spherical roller bearings.



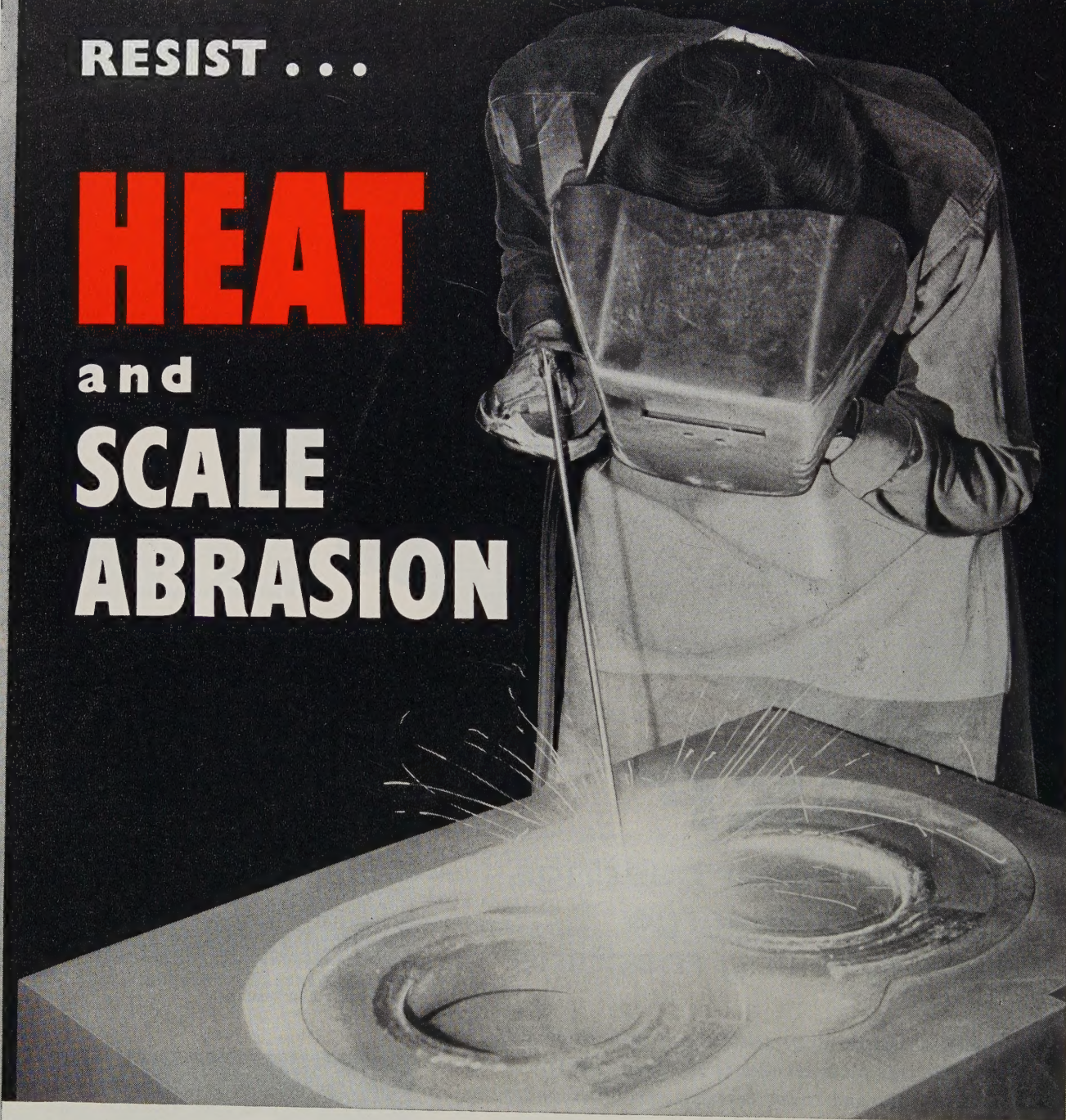
Backing rolls with special heavy duty housings for spherical roller bearings.

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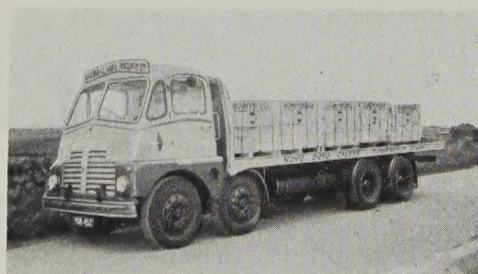


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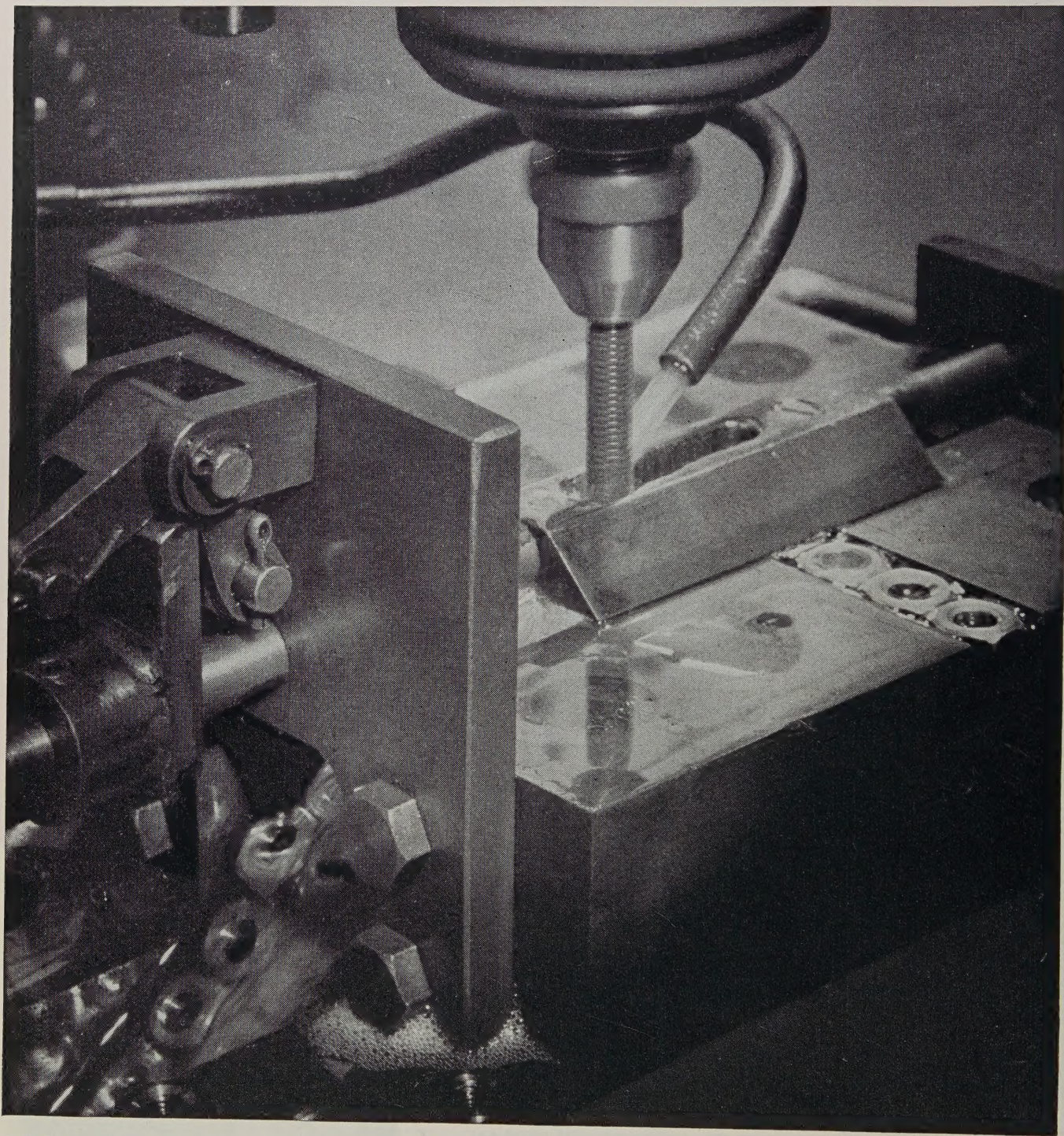


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Shell achievement



A famous aero-engine firm found it could drastically reduce the cost of producing nuts made from S.62 steel, by changing over from conventional cutting oils to Shell Garia Oil 115. The facts are these. S.62 steel is heat-resistant and stainless. The quality of this steel and the call for very fine tolerances, as well as a very high percentage of full depth of thread, presented costly manufacturing problems. The breakage of taps, the need for constant re-setting, and the high proportion

of rejects, built up the average cost of the nuts to over 1s. 2d. each.

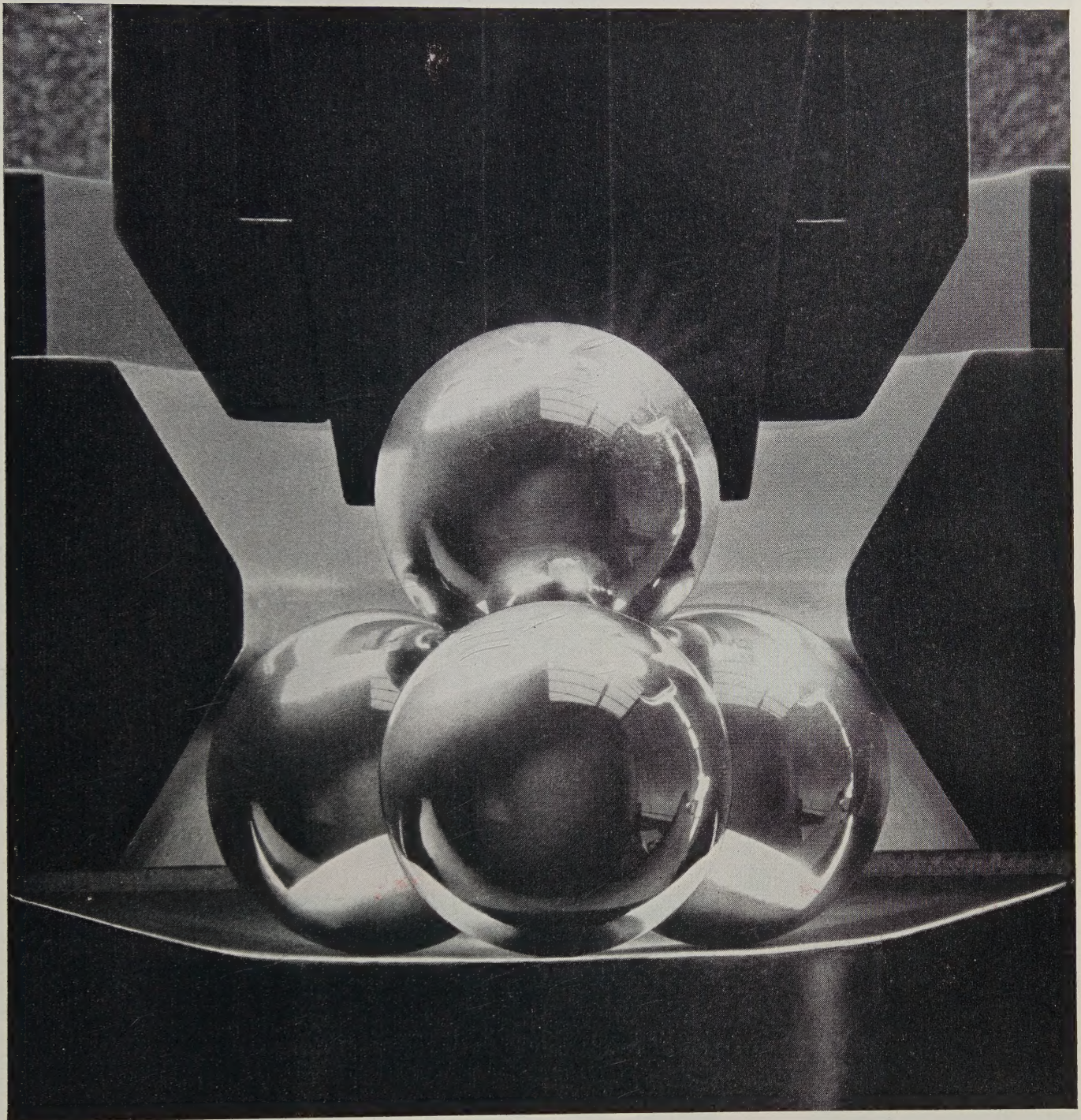
By accepting the advice of the Shell engineer and changing over to Shell Garia Oil 115, this firm was able to produce 3,000 nuts between regrinding taps—resulting in the cost of each nut being reduced to 3d.

Write for the booklet 'Selecting Your Cutting Oils' to Shell-Mex House, London, W.C.2.



SHELL INDUSTRIAL OILS

Shell demonstration



To establish *facts* is the constant preoccupation of Shell research. Assumptions cut no ice. For example, how 'extreme' is 'Extreme' Pressure? To evaluate scientifically the respective performance of the many E.P. agents evolved, Shell devised the Four Ball Test machine illustrated. In this apparatus a clamped $\frac{1}{2}$ " diameter steel ball revolves in contact with three identical static balls in a metal cup containing the additive to be tested. Pressure between the balls can be varied at will. Under these controlled rubbing conditions, coefficients of friction

can be plotted against load. With increasing loads, wear scars formed at successive stages may be measured and the welding point accurately determined. Developed for basic research, the Four Ball Test also plays an important workaday role in ensuring consistent batch quality—of prime importance on the machine-shop floor.

Thoughtful production executives who want to know more have only to write for the book, *'Selecting Your Cutting Oils'*, to Lubricants Dept., Shell-Mex House, London, W.C.2.



SHELL CUTTING OILS



STEIN *Refractories*

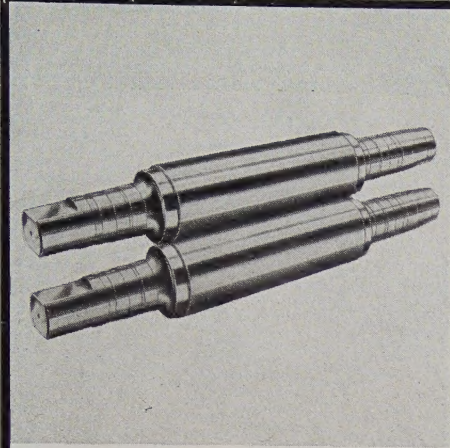
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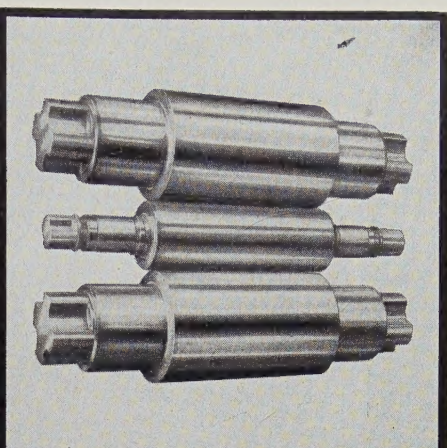
JOHN G. STEIN & CO. LTD. Bonnybridge, Scotland. Telephone BANKNOCK 255 (4 lines)



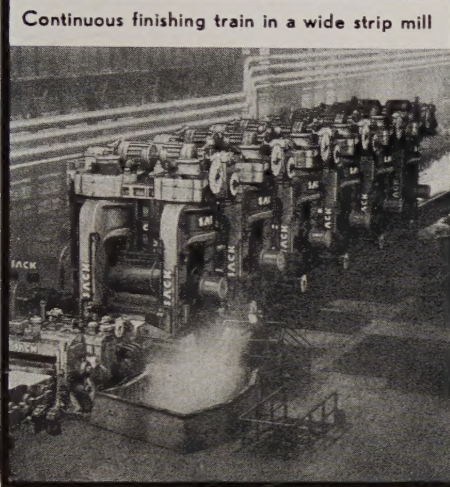
Work rolls 27" x 83"



4-high plate mill



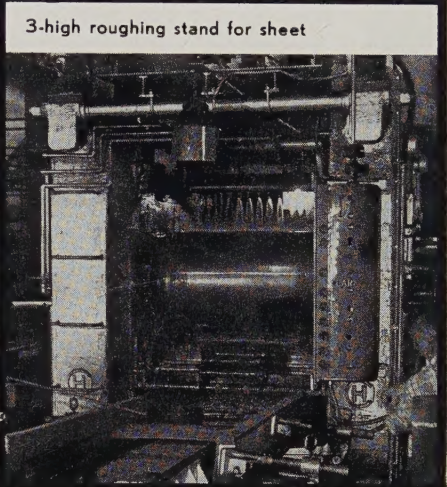
Rolls 32" x 53 1/2" and 20" x 59 1/2"



Continuous finishing train in a wide strip mill



Work rolls 35 1/2" x 150"



3-high roughing stand for sheet

Åkers rolls for plate and strip steel give lower costs per rolled unit

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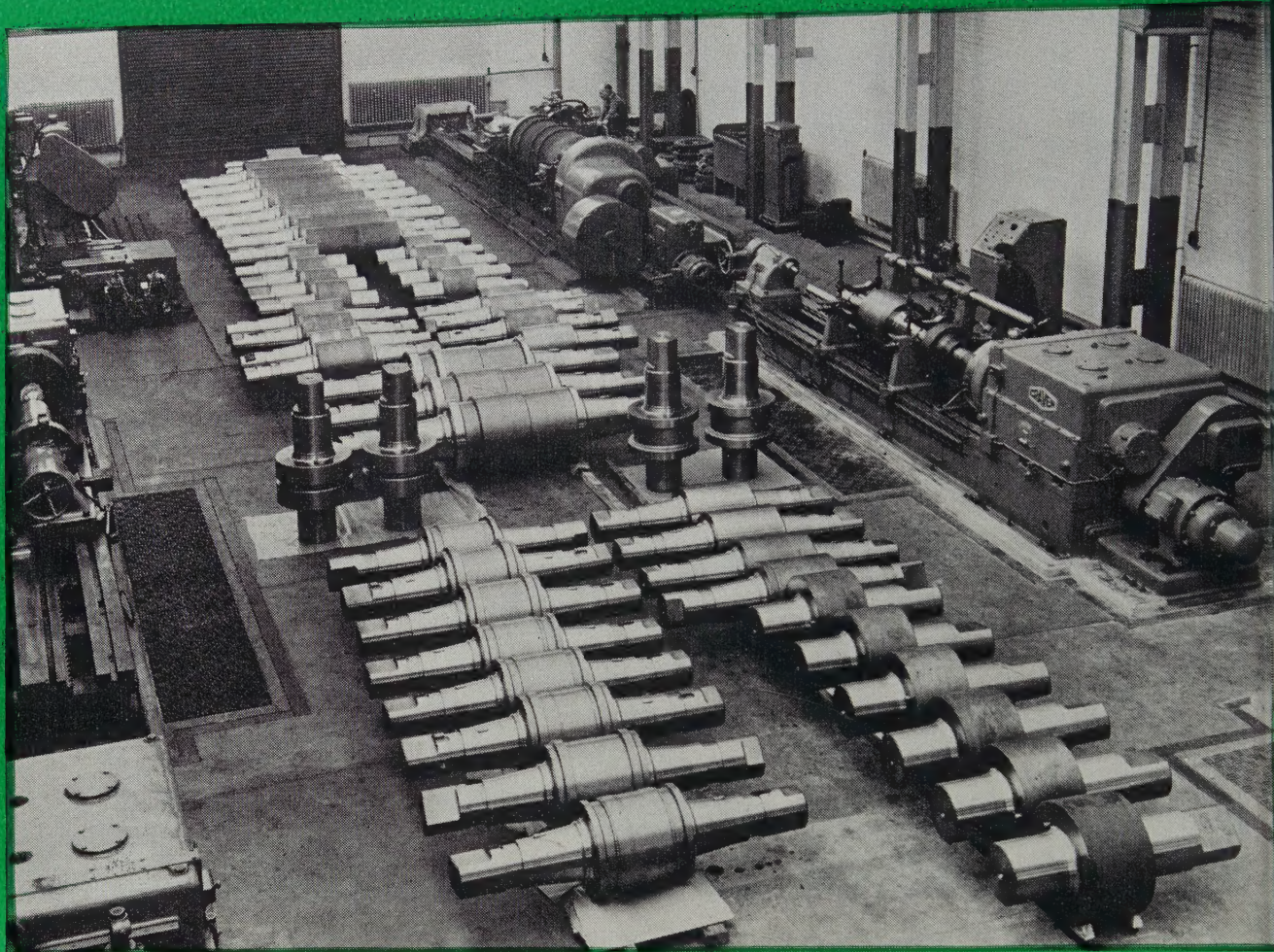
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The above is one of the many consignments of rolls forming part of the complete initial fillings and spares we have manufactured in Our Specially Toughened Alloy Spheroidal Graphite and Moor alloy Qualities for the Morgan Billet, Sleeper Bar and Slab Mill at DURGAPUR, WEST BENGAL.

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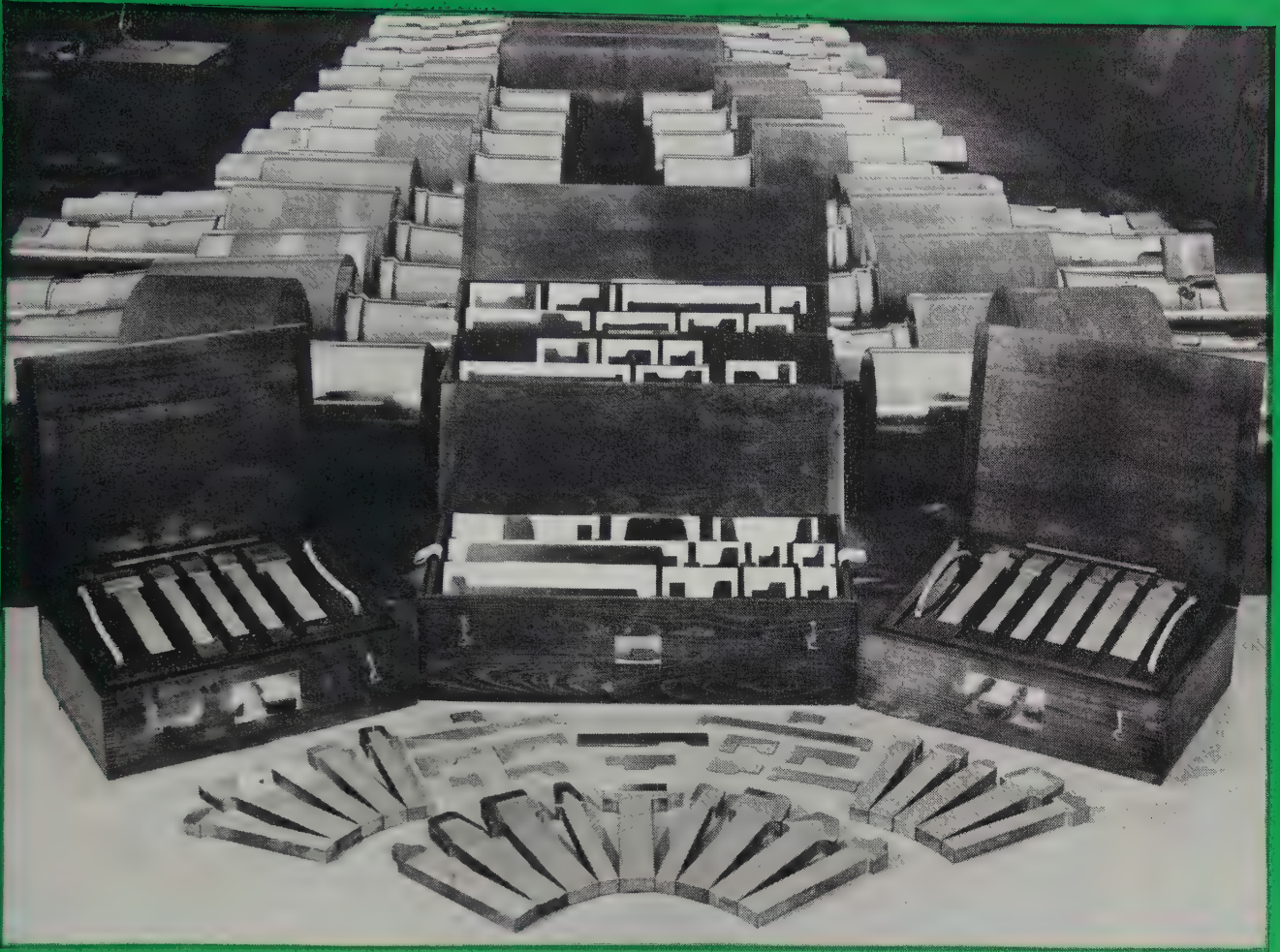
On the opposite page we show the principal grades of OUR SPECIALLY TOUGHENED SG ROLLS and OUR SUPER METAL MOORALLOY ROLLS but each of these quality ranges are again subdivided to suit requirements.

PLEASE CONSULT US SO THAT WE CAN ADVISE YOU

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From experience Gibbons "H.T 1" insulating refractory is the automatic choice of leading furnace manufacturers and users—its combination of low thermal conductivity with resistance to high temperatures has proved remarkably effective in minimising heat losses and raising furnace outputs. The Gibbons "H.T 1" is developed from more than 20 years' experience in the manufacture of insulating refractories and today an entirely new and original manufacturing technique enables us to offer material having unique physical properties at a price you can afford to pay.



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A view of the Escher Recupercators installed on three Forge Furnaces at Walter Somers Limited.

A view of the line-up of Escher Recupercators installed on 5 Continuous Furnaces at The Steel Company of Wales Limited, Port Talbot.

A view of the battery of 10 externally sited Escher Recupercators on the soaking pits at the Middlesbrough plant of South Durham Steel and Iron Company Limited.

Nearly 1,000 Escher Recupercators

—by turning waste heat into preheat—

are cutting the cost of world steel production

S&A Escher Recupercators—accept gases at full furnace temperature: provide high preheat temperatures for air and gas: incorporate automatic safeguard against overheating: include a simple and tight damper system without leakage or loss of draught: eliminate the need for a separate chimney or excavations: have no "hot spots": are of such a configuration as to prevent slag or dust deposits: provide easy access to all parts making for low maintenance costs. These advantages combined with Escher reliability explain the continuing demand. May we visit you to also discuss the Hollow Fin Escher Recupercator?

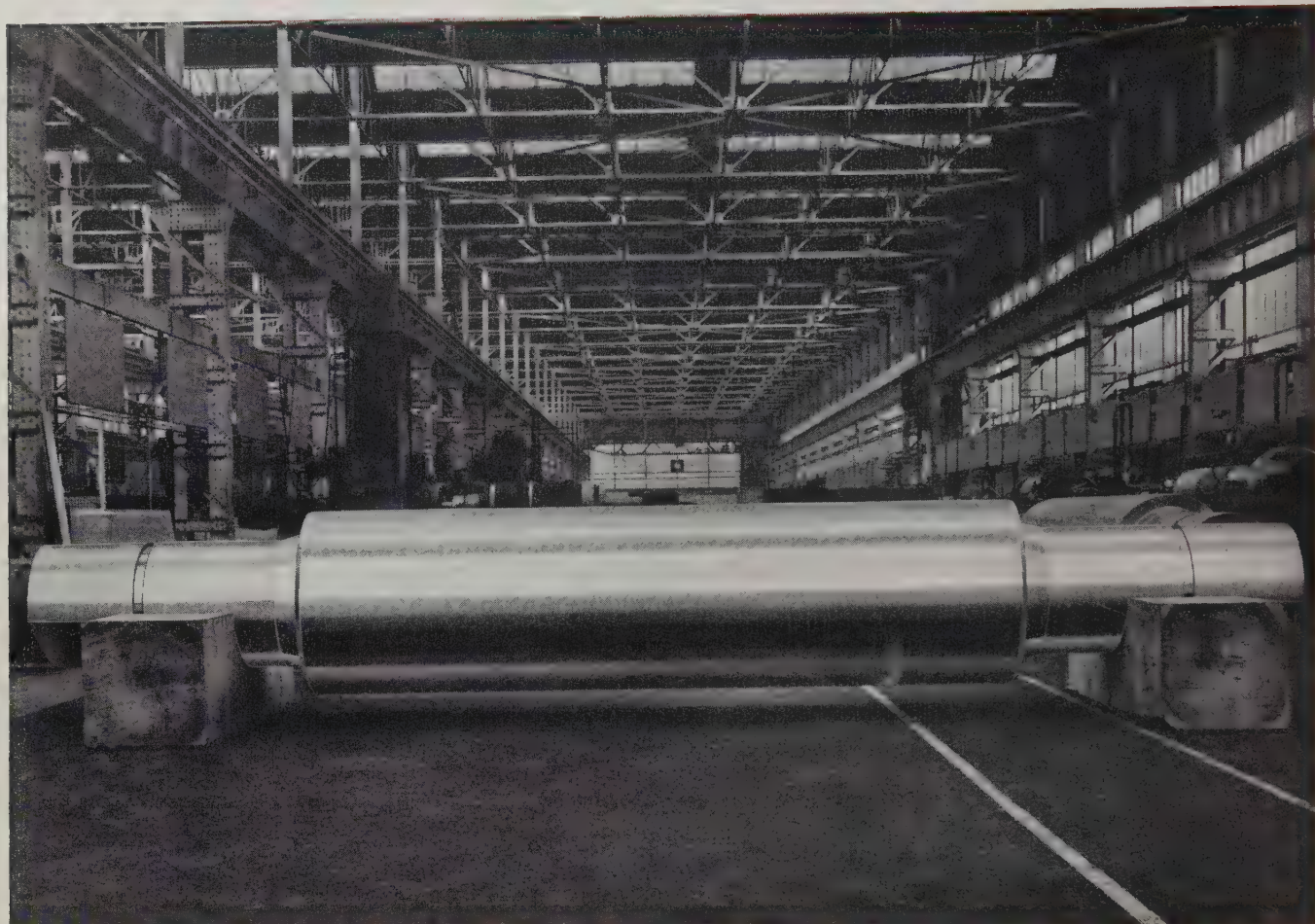


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CRAFTSMANSHIP BY THE TON



This heavyweight turned the scales at 28 tons, $10\frac{1}{4}$ cwts. It is a Duplex Manganite Alloy Indefinite Chill Work Roll, $39" \times 150" \times 266"$, for a 4 High Plate Mill. From this, to the smallest work roll, you can rely on us for accuracy and quality.

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...the ruling which entails Class...
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...not to re-engage for this week's...
...found berths on other...
...They have found plentiful with a...
...number of crews switching over to...
...herring fishing.

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...classrooms for those interested in...
...appeals for those interested in...
...the school, as subscribe and ensure...
...the hub of the school will not only...
...be fit for reoccupation in 1963 but will...
...also contain within its classic walls...
...these much-needed amenities...
...Donations can be sent to the Earl of...
...Mar and Keilis at the Clydesdale &...
...North of Scotland Bank, Ltd., Dollar...
...Cheques should be made payable to...
...the Dollar Academy Restoration Fund.

GLASGOW MAN STABBED
John Ross, a bleach factory worker, was stabbed during a scuffle at a public-house in Abercrombie Street, Glasgow, yesterday. Police prevented customers from leaving, and the injured man, who lives at 22 Hopehill Road, Maryhill, was rushed to the Royal Infirmary. His condition is serious.

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area be developed primarily as a...
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customers at home and abroad

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*

*Photograph by courtesy
of the Steel Company of
Wales Ltd.*

A RECORD ACHIEVEMENT WITH

GR SUPERMAG

*

No. 5 Mixer (1,200 tons capacity) in the VLN Steel Plant at the Abbey Works of the Steel Company of Wales Ltd.

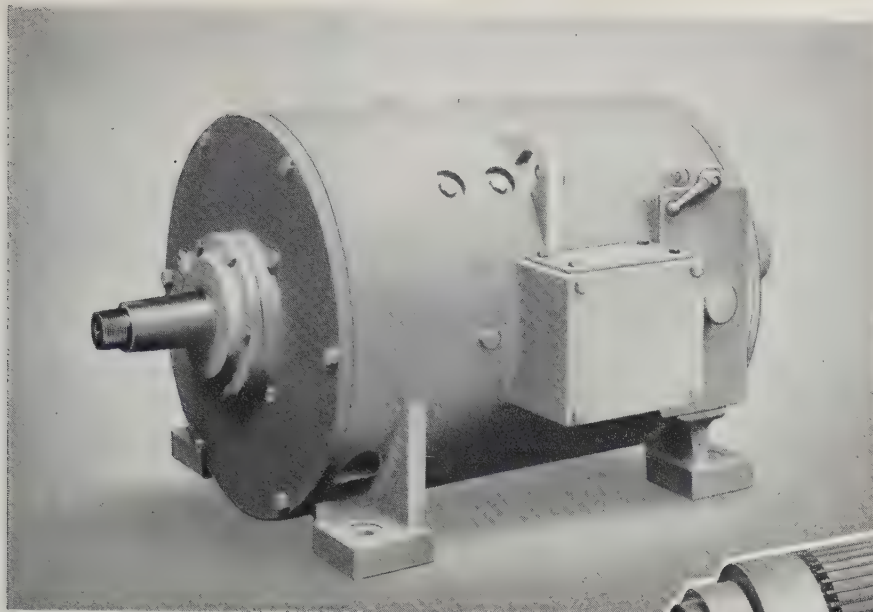
A record throughput of 530,304 tons of metal has been reached on No. 5 hot metal mixer in the VLN Plant at the Abbey Works of the Steel Company of Wales—an all-time 'high' in the history of British Steelmaking and the first time the half-million ton mark has been reached in the U.K.



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GENEFAX GROUP
for everything
in Refractories

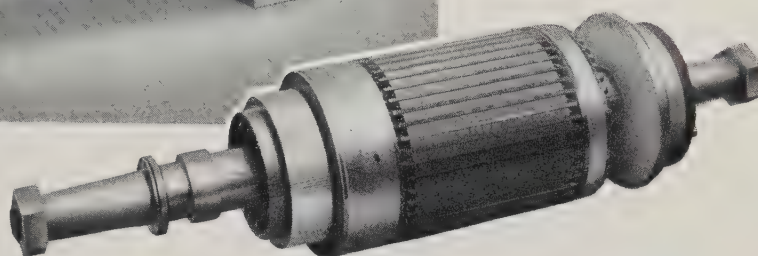
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Motors are reversible about the centre line. Cable tails or terminal boxes (entry from either side) may be provided. Large dust-proof inspection covers are fitted, and the brush assembly can be rotated to facilitate maintenance.

Shafts are double-ended. The armature is most rigidly constructed and the insulation incorporates glass, polyester film and mica.



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mechanically interchangeable with motors to A.I.S.E. standards

For many heavy-duty d.c. motor applications which may necessitate speedy replacement of a damaged armature, the costly split-frame construction is unnecessary, since a complete motor can be replaced as quickly as an armature can be withdrawn and another substituted.

With this in mind, L.S.E. have developed a range of d.c. motors which are interchangeable with equivalent motors to A.I.S.E. standards, are mechanically and electrically as robust as the most arduous duties demand, and offer considerable price advantages.

Termed the 'Dreadnought' range, these motors are available either totally enclosed (1-hour rated) or forced-ventilated, and can be supplied weatherproof, for outputs up to about 200 h.p.

Fuller details are given in Publication 168, available on request to: Laurence, Scott & Electromotors Ltd., Publicity Dept., 376 Strand, London W.C.2.

For use where a split-frame is considered essential, L.S.E. mill motors, including motors to A.I.S.E. standards, are still available.



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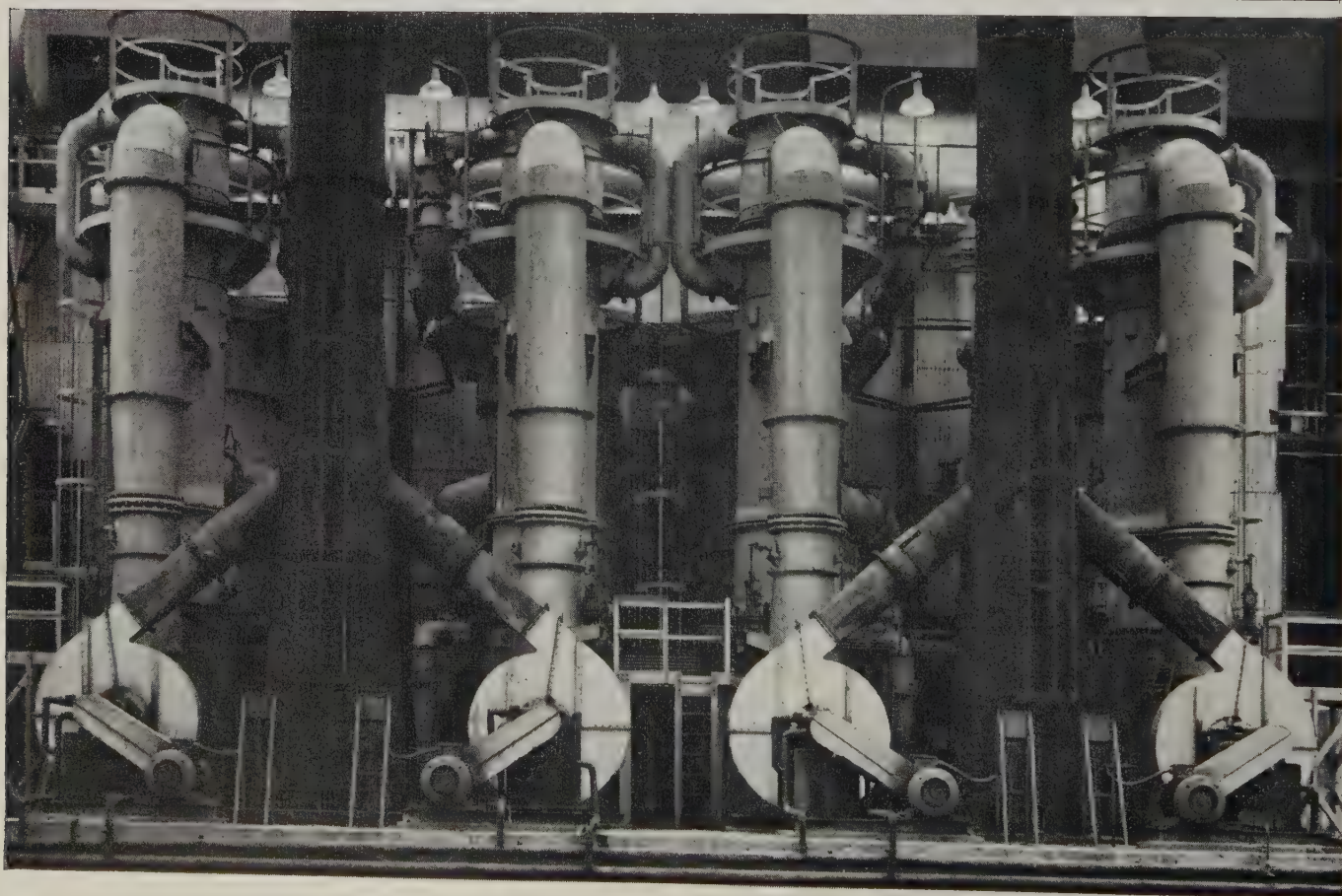
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Four one-way fired soaking pits
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Installed by Messrs. Wellman Smith
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for Messrs. Richard Thomas
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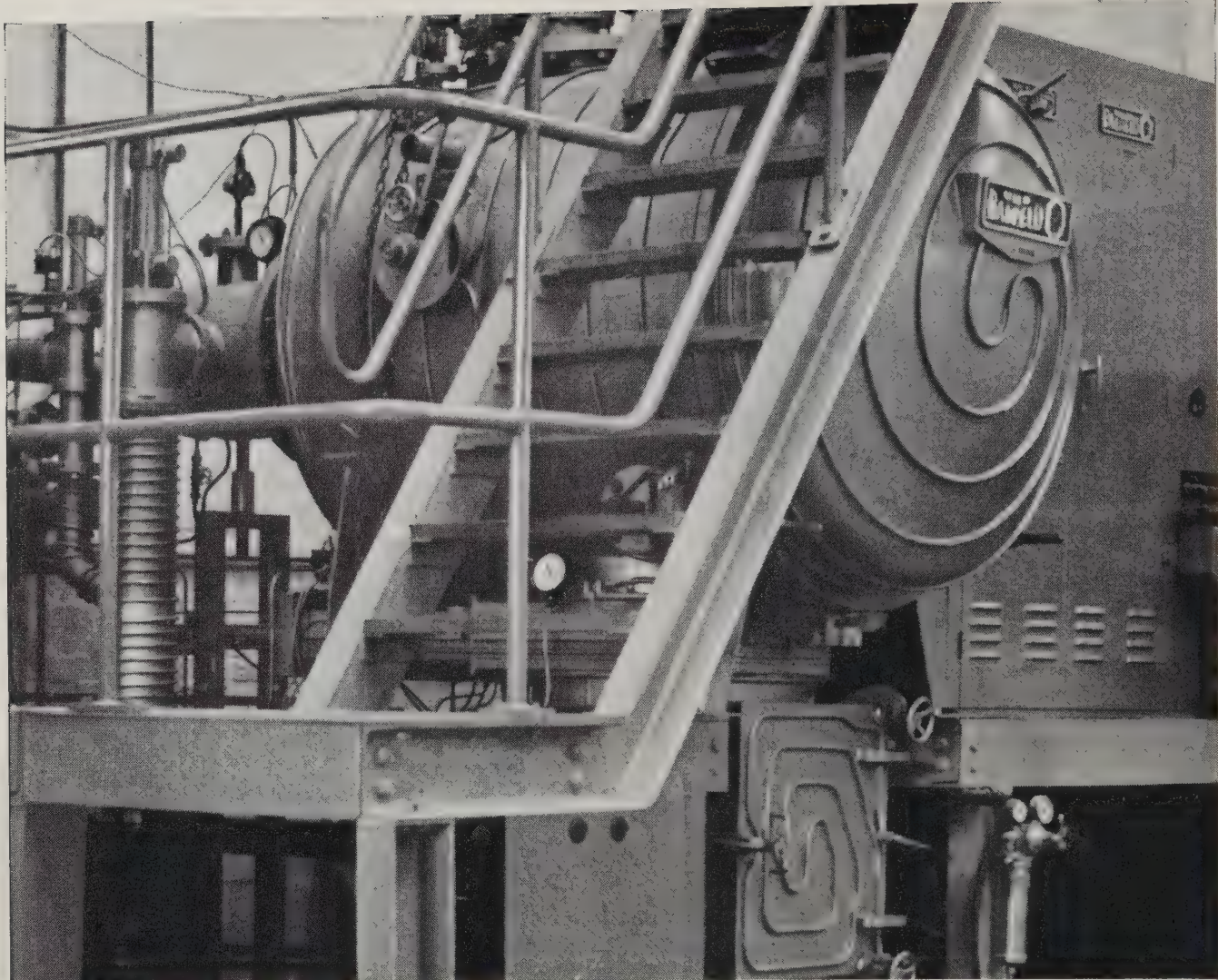
Write for Catalogue Ref. 120/19 giving full details of

RENOLD STOCK CONVEYOR CHAINS

WITH ATTACHMENTS FOR ALL DUTIES

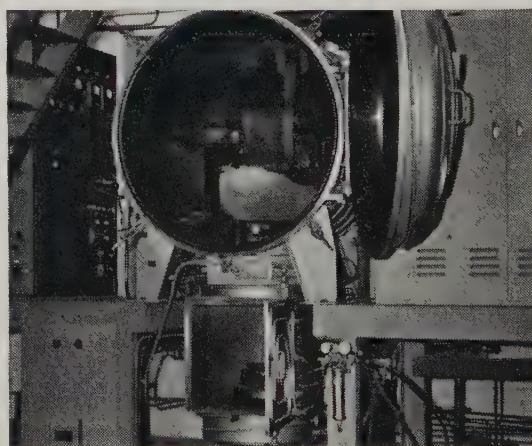


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Vacuum Induction Furnace at Bristol-Siddeley Engines Ltd.

Increased output of jet engine components. That is briefly the result of installing this 50 lb. (molten steel) capacity Wild-Barfield-NRC vacuum induction melting furnace at Filton. Bulk charging and mould locks enable semi-continuous production to be maintained. In fact, the weekly output of this one equipment is greater than that of five vacuum arc furnaces used for similar work. If you have a vacuum application, remember that the experience of Wild-Barfield covers the design and manufacture of all types and sizes of vacuum furnaces.



FOR VACUUM METALLURGICAL APPLICATIONS

WILD-BARFIELD ELECTRIC FURNACES LIMITED

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WB114

Steel-making in Wales

Mitchell conveyors have been carrying raw material into the blast furnaces of Wales day in, day out since 1937

Just a single Mitchell tippler and conveyor system at one Welsh steelworks has been handling 15,000 tons of coal, coke, ore and sinter a day for many years.

And now Mitchells are well advanced on a £2,500,000 contract for a new materials handling system at Richard Thomas and Baldwins' new Spencer Steelworks near Newport.

Mitchells are also active in the fields of boiler design, cableways and ropeways, wagon handling, transporters and conveyors, cranes, mills, ship loading plant and nuclear power.



This Mitchell conveyor carries ore to Britain's biggest blast furnace

MITCHELL

MITCHELL ENGINEERING LIMITED • ONE BEDFORD SQUARE • LONDON



Coal has a bearing on

PROGRESSIVE INDUSTRY IS GOING FORWARD

Vandervell success

Our modern world would grind to a halt without the thin wall bearing, which tames the destructive powers of friction and allows metals to revolve at high speeds without burning out. So precise and demanding are its tasks that its manufacture is the highly specialised work of Vandervell Products Ltd., whose famous bearings—supplied as original equipment to manufacturers in 15 countries—are constantly on duty on the land, on the sea and in the air.

Obviously the shrewd men who control such a thriving concern have a flair for making long-term decisions that are both wise and profitable. Vandervell choose coal because all their experience has proved that *coal*, the home-produced fuel, gives them all the steam for power they need at the lowest possible cost. They know that coal—mechanically stoked—is smokeless; they know that our coalfields contain all the coal that industry can use for scores of years to come.

When it is your duty to make a decision about fuel, remember Vandervell. They choose coal. The same choice could well help your business to run more smoothly.

ON COAL

Coal begins the complex processes
which give industry its vital bearings

The Engineering Manager comments

"Vandervell Products Limited of Acton, West London, make Thin Wall Bearings and Bushings for the majority of the motor industries of Europe and supply original equipment to fifteen nations. The new works at Maidenhead, which now constitute the most important productive unit, use coal for the boilers.

The modern boilerhouse contains 3 high velocity two pass Economic boilers. The first produces steam at 65 p.s.i. reducing to 45 p.s.i. for process work in the factory, supplying heating coils in plating vats and de-greasing tanks. Maximum capacity is 10,000 lbs. of steam per hour, with a weekly average consumption of a little over 24 tons of coal. Steam production is just under 500,000 lbs. with about 95 per cent condensate return at a temperature of 150°F.

The other two boilers supply the low pressure hot water heating system for the works and offices. Each boiler has a capacity of 10,000,000 B.T.U./Hr. and operates at 27/30 p.s.i. The circulating system is by pumps although there is also a static water head of 30 ft. should both pumps fail, and a 60 ft. expansion safety head. The circulation rate is 40,000 gallons/hr.

The average temperature aimed at in the works and offices is 62°F. with unit heaters and gilled tubing respectively comprising the heating source. A calorifier fed from the steam boiler supplies hot water for kitchen use and in the toilets.

Coupled with high thermal efficiency is the completely smoke-free operation of all the boilers, which are fired by chain grate stokers, burning Eastwood washed smalls. A smoke density indicating device automatically rings an alarm bell and flashes a red warning light when flue gases rise above Ringelmann 2. Coal is mechanically conveyed from the storage point below ground by an elevator which carries the fuel to a cross-conveyor which feeds the large hoppers down to the stokers. Fuel deliveries have always been 100 per cent reliable. Even during the worst and foggiest periods of winter, one hundred tons were brought in each week with unflinching regularity by road, direct from the colliery."

Here are some key facts and figures about the consumption of coal by Vandervell Products Ltd.

No. of boilers:.....3 high velocity economic
Method of firing:.....chain grate stokers
Steam pressure:.....100 p.s.i.
Steam temperature:.....334°F.
Max. continuous rating (1 boiler):.....10,000 lbs./hr.
Annual fuel consumption:.....3,200 tons

**SOLID FUEL—more heat at
less cost—and it's British**

HOT ROLLED STEEL BARS

Round • Square • Flat

Ferro-Concrete Bars *bent to Specification*

.....

HOT ROLLED STEEL HOOPS AND STRIP

Coils or cut lengths

.....

COLD ROLLED STEEL STRIP

in all qualities including

**Special Deep Stamping
in cut lengths or coils
Electro-Galvanised Strip**

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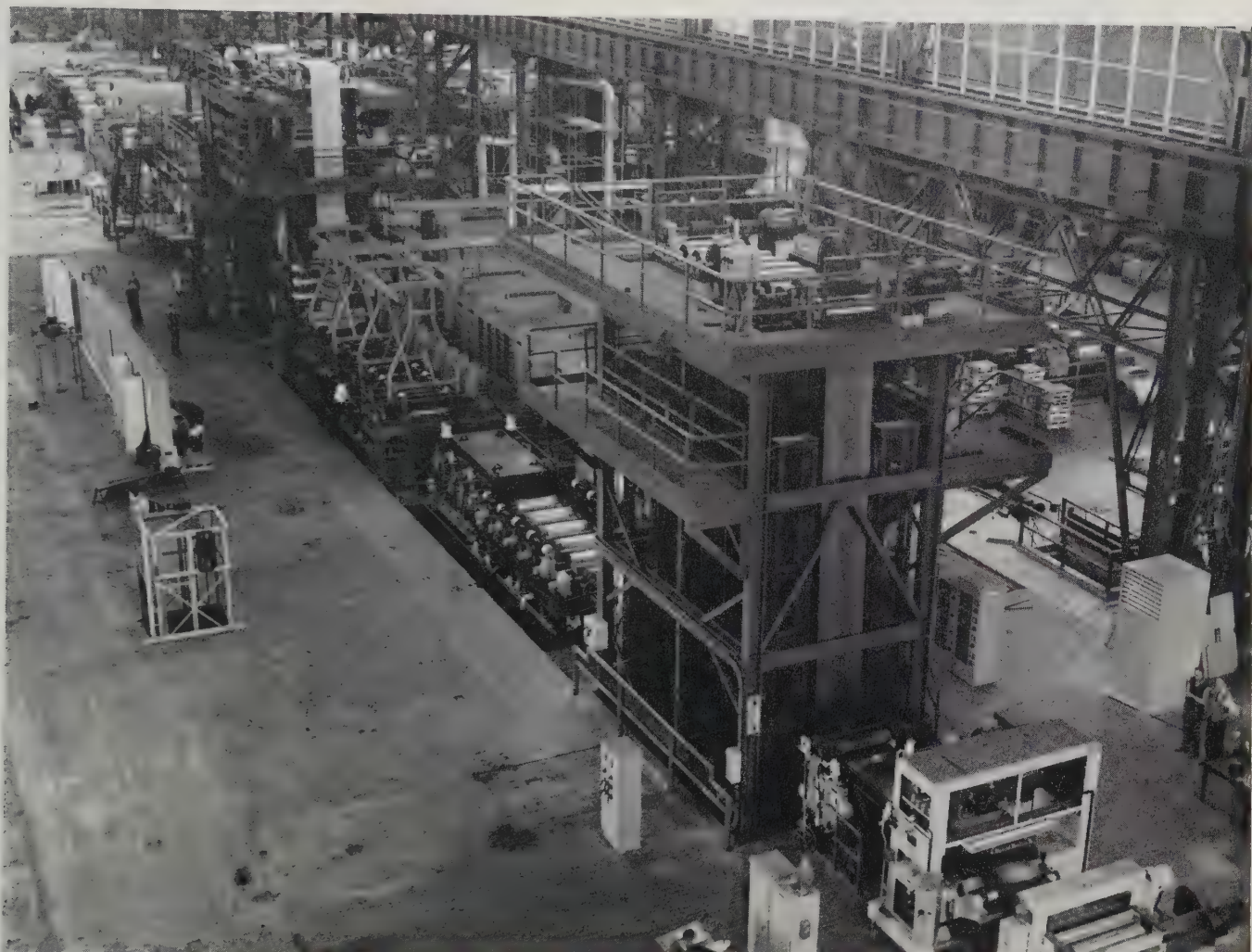
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Another Electrolytic Tinning Line for Britain

The sixth Ferrostan electrolytic tinning line of Wean design to be installed in a British steelworks has now been commissioned for operation at the Trostre Works of The Steel Company of Wales Ltd.



Photograph by courtesy of The Steel Company of Wales, Ltd.

WEAN-MILES LTD., designers and builders of equipment for British sheet and tinplate mills, are at present completing the engineering, manufacture and installation of new lines for:—

CONTINUOUS TINPLATE ANNEALING · CONTINUOUS STRIP PICKLING ·
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All this equipment is engineered and built to the designs developed by Wean, and incorporates specialized units of British design. British manufacturing facilities, labour and skill are employed throughout.

Wean-designed pickling, electrolytic cleaning, annealing, tinning, galvanizing and shearing equipment is extensively used throughout the world for processing and finishing tinplate and sheet-mill products, including stainless and silicon steels.

Their experience gained from close co-operation with the steel industries of the world for over 30 years is embodied in the equipment built in Britain by Wean-Miles Ltd.

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EUROPE'S LARGEST WALKING DRAGLINE...

RAPIER-built for faster mining of South Wales anthracite

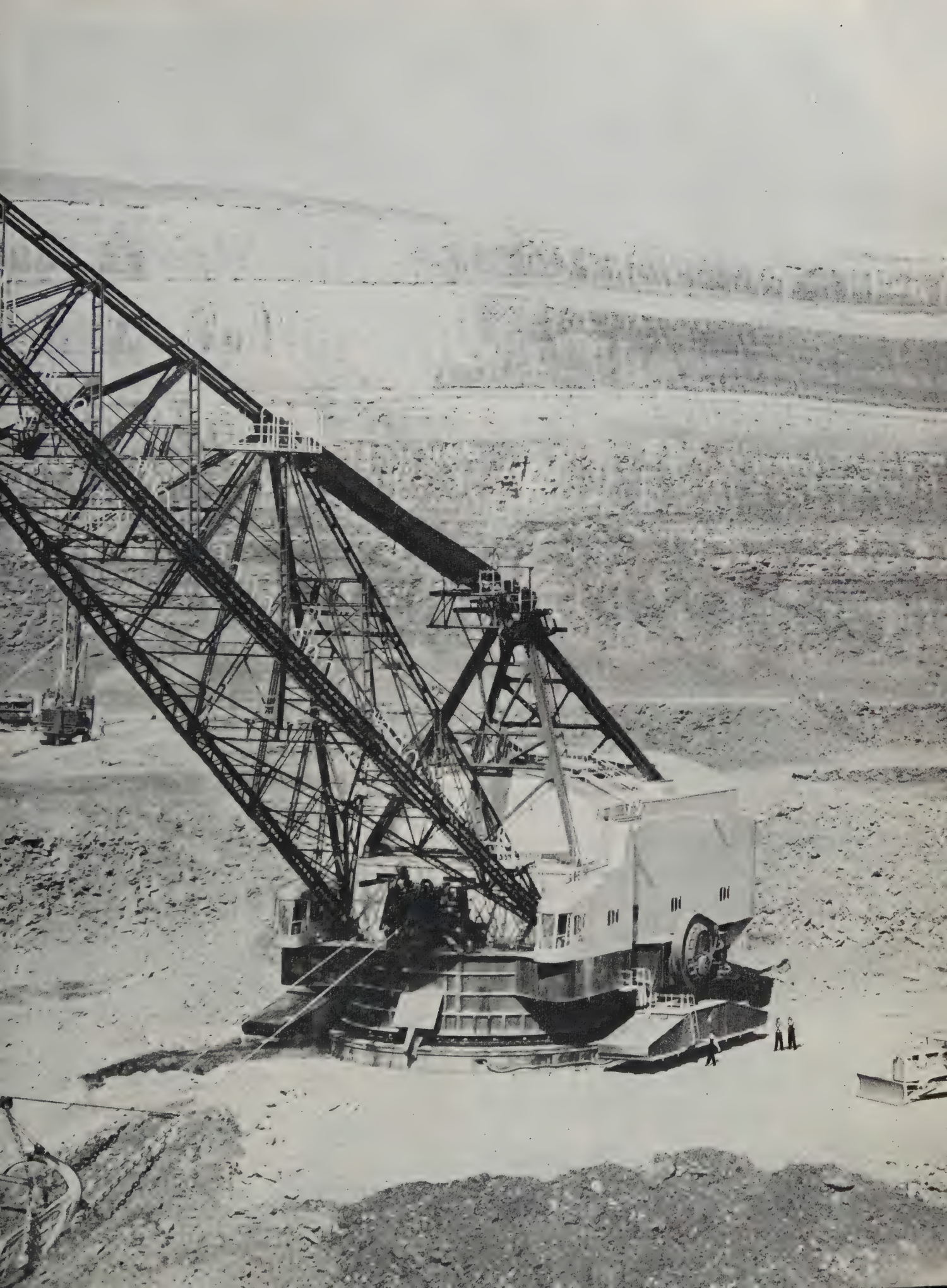
This mammoth Rapier W.1800 walking dragline, now digging, lifting and dumping 60 tons of rock and earth a minute at the Glyn Neath workings of the National Coal Board, weighs 1800 tons and operates a 40 cu. yd. bucket from its 247-ft. boom. It is being used by contractors George Wimpey, stripping over-burden to expose beds of high quality anthracite 300 ft. below the surface.

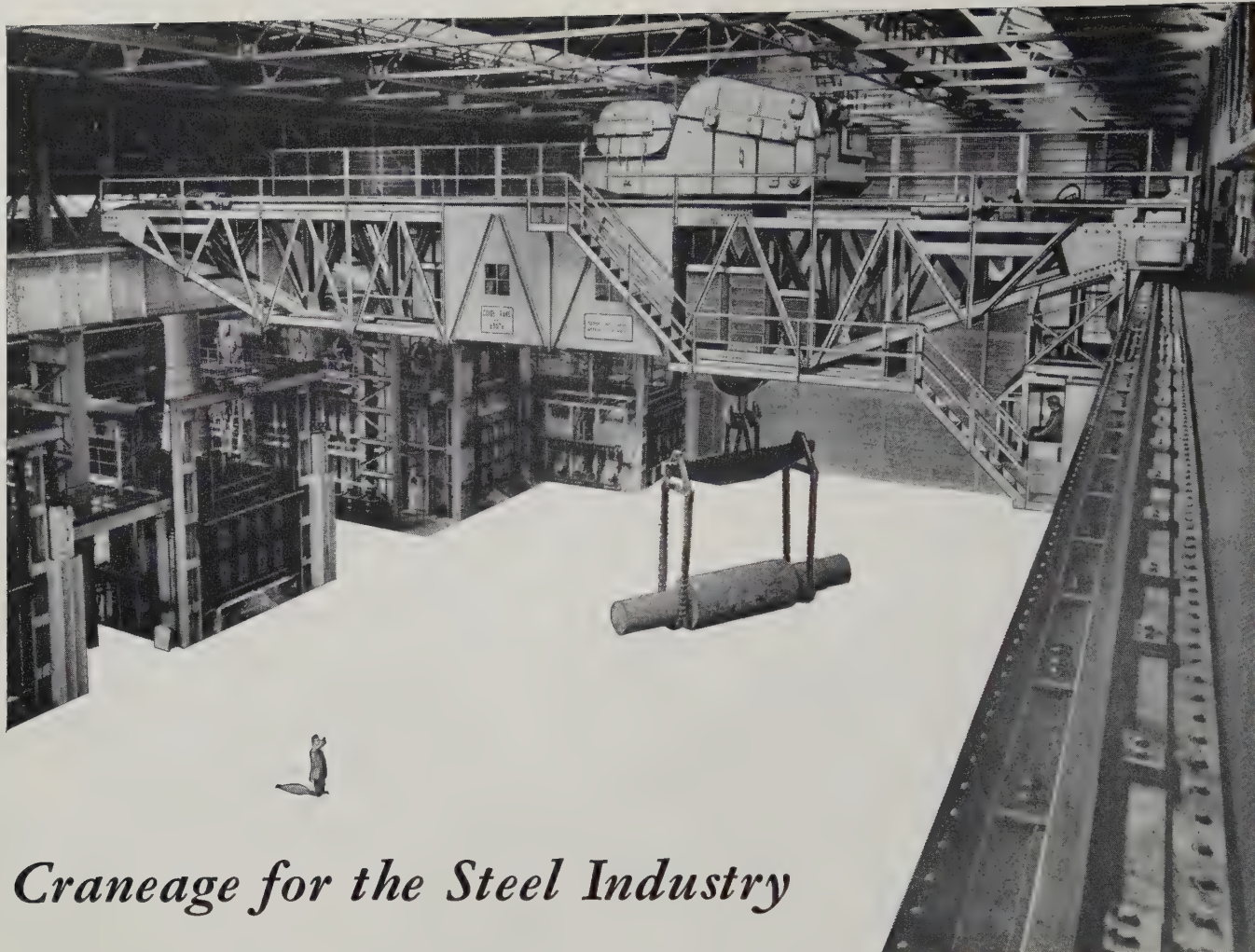
The machine was designed and built by Ransomes & Rapier, backed by the great engineering resources of the Newton Chambers Group of Companies. They are the only British organisation among the three or four in the world who produce excavating machinery of this size. Rapier walking draglines are at work from Australia to Scandinavia, from Africa to North America.

RANSOMES AND RAPIER LTD IPSWICH ENGLAND

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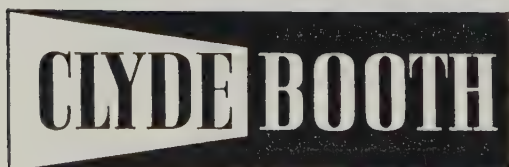
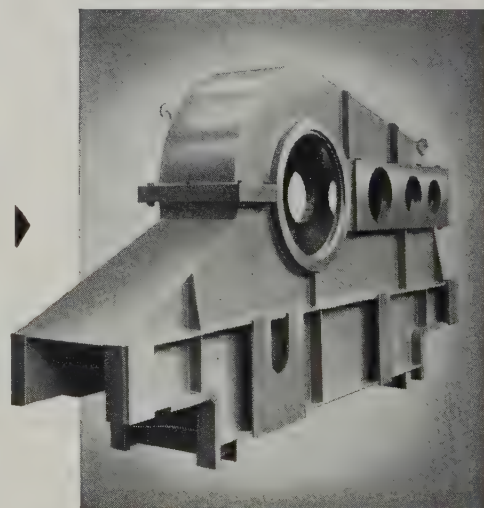


Upper photograph by courtesy of Messrs. Thomas Firth & John Brown Ltd.

Craneage for the Steel Industry

A 130/40 tons heavy duty electric overhead travelling crane handling forgings in the Bessemer Heat Treatment Department at Messrs. Thos. Firth & John Brown Ltd., Sheffield.

Fabricated steel gearboxes are a salient feature of Clyde-Booth practice. In this example the gearbox and crab side members form a monobloc box-section of great strength and rigidity.



CLYDE CRANE AND BOOTH LIMITED

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Joseph Booth & Bros., Union Crane Works, RODLEY, Leeds. Tel: Pudsey 3168. Grams: 'Cranes Rodley Telex'. Telex 55159
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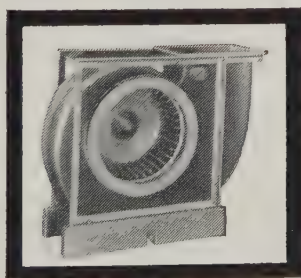
FB 1



SAFELY AND SURELY

Pumps and Stirrers for corrosive liquids. Fans for acidic fumes. These Kestner make—and have made for years—to meet every need of the chemical and allied industries.

CONSIDER PUMPS Kestner originated continuous pumping by compressed air. They made obsolete the old acid egg by producing the Kestner Acid Elevator. They followed this up with the first of their Glandless Pumps which have now been manufactured for over 50 years. They make, too, an impressive range of Horizontal Pumps, with glands and mechanical seals, a range constantly augmented and modified to meet specific demands. But Kestner don't stop there — they supply the Rotopump, easily carried and ideal for smaller quantities of acid, and they make the emptying of glass carboys a hazardless, simple matter with the Oldbury Patent Carboy Discharger. The emphasis, of course, is acidic. Kestner, after all, developed



Keebush, the supremely anti-corrosive plastic. And many of their pumps are made of Keebush. But the really important thing is that Kestner select the design of the pump, and its material, on the needs of each specific task.

SO TO FLUID MIXING A basic industrial operation for which Kestner supply stirrers of varying sizes, propeller or turbine, in whatever material is appropriate. Kestner Stirrers obviate corrosion and erosion. They are simple in design and enduring in use. They are consistent and trouble-free. Viscosity can be low, or extremely high. The mixture may be corrosive or not.

Large or small a Kestner Stirrer gives the highest efficiency for the power consumed.

NOW TO KESTNER FANS In Keebush, Keeglas, Lead or P.V.C. Acidic fumes and vapours are reliably handled. Fume extraction and corrosive gas handling are operations safely and easily carried out.

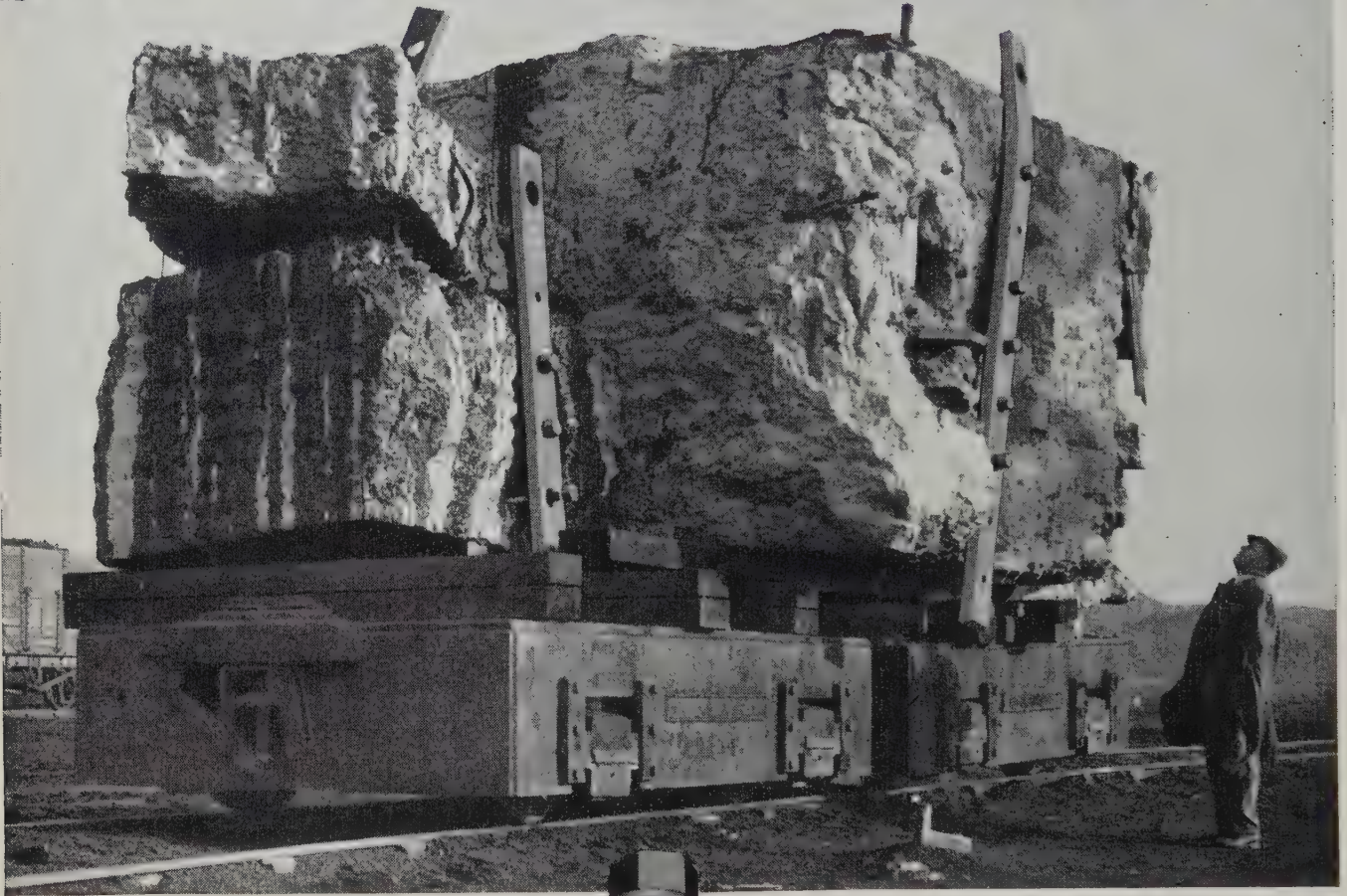
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RAWLBOLTS LIFT 100 TON BLOCKS



From Corby comes yet another impressive demonstration of the tremendous grip of Rawlbolts. Here, old concrete foundations had to be cleared for the installation of a new steel mill. They were burst with hydraulic cartridges, then trenched and drilled for $1\frac{5}{8}$ " diameter bolts, reduced and screwed to take K.20 Rawlbolt Shields. By this means removal was carried out in record time.

We are indebted to Stewarts & Lloyds, Ltd., of Corby, Northants, for the above information and permission to use their photograph.

FIXED IN MINUTES

Rawlbolts grip by *expansion*. You drill the material, insert the Rawlbolt, tighten up. The job is ready to take its full load *at once*—no grouting in, no waiting for cement to harden. A Rawlbolt fixing is made in a fraction of the time taken by any other method. Sizes and types for every purpose.

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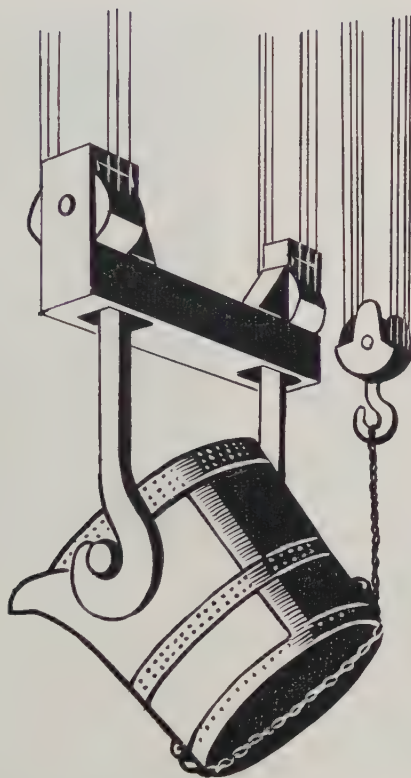
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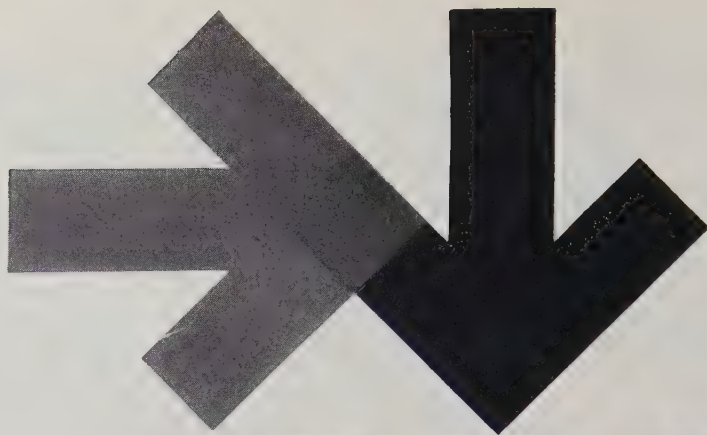


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27 breakdowns in seven years. The cause? Insulation failure. The electric motor on a four-ton stripper crane at Workington Iron and Steel Company kept breaking down, so in 1953 the 50 hp Class A motor was replaced by a Class B insulated motor of the same rating specially designed for heavy duty—but there were still 5 insulation breakdowns over the next three years.

Because of production losses and the cost of rewinds the motor was finally rewound in 1956 with Class H insulating materials—silicones combined with glasscloth and mica.

Result? In the words of Workington Iron and Steel Company, 'No breakdowns since that date'. A saving of £2,000 in rewind costs with *no* further losses in production due to insulation failure.

Contact your Midland Silicones area office and ask for a list of manufacturers and rewinders experienced in silicone insulation and for copies of our regular news bulletin "MS News for Industry."



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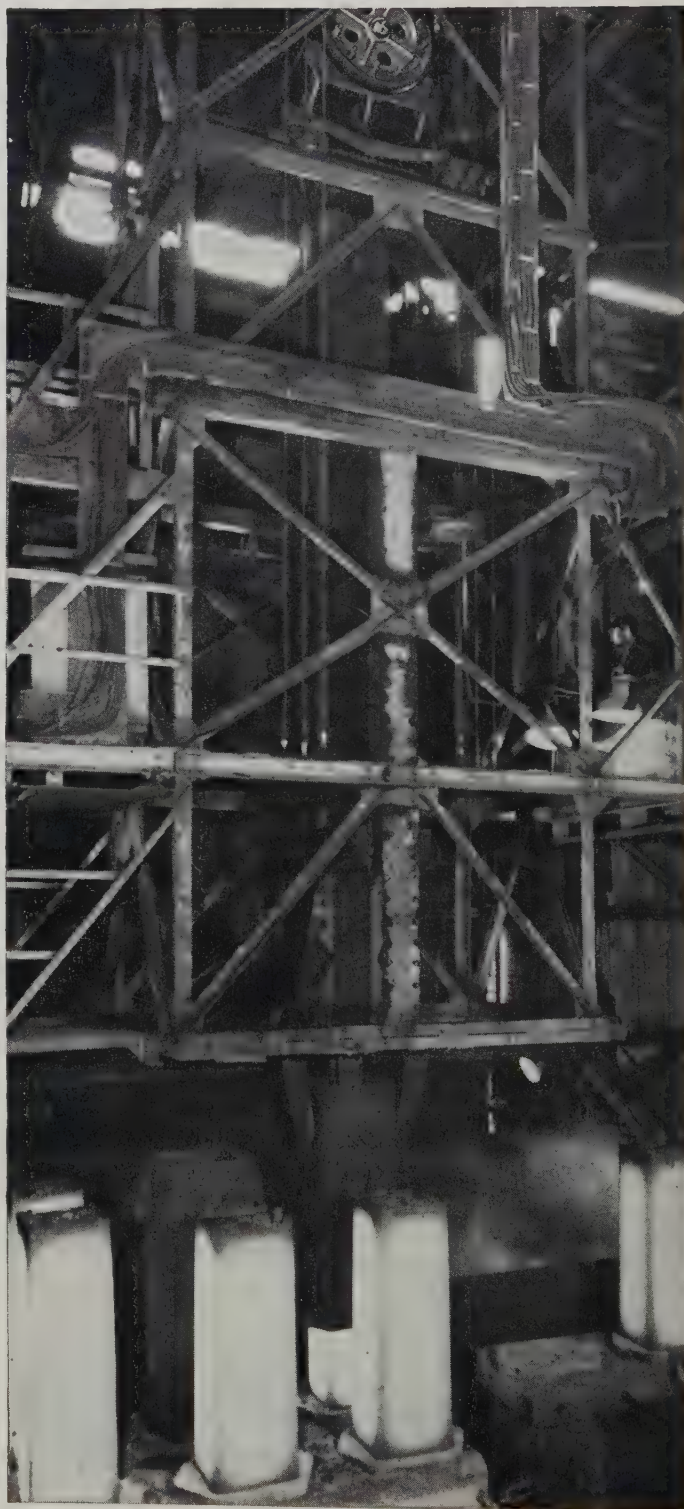
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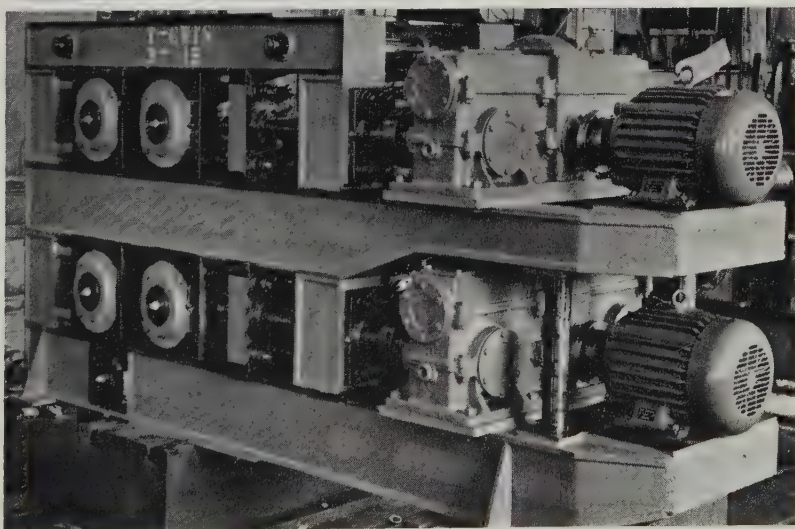
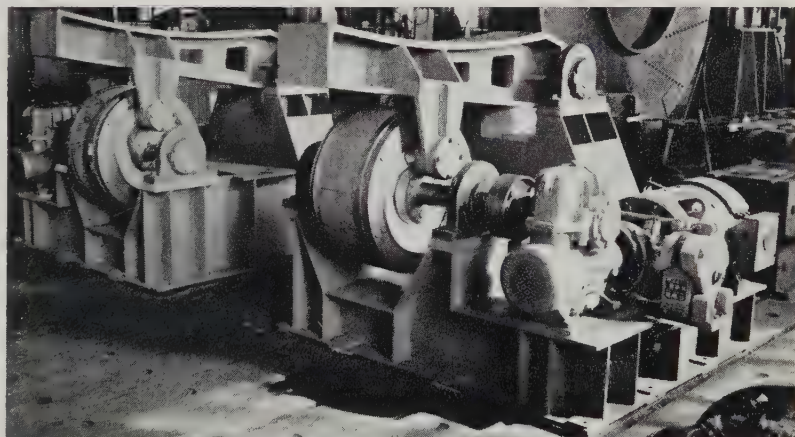
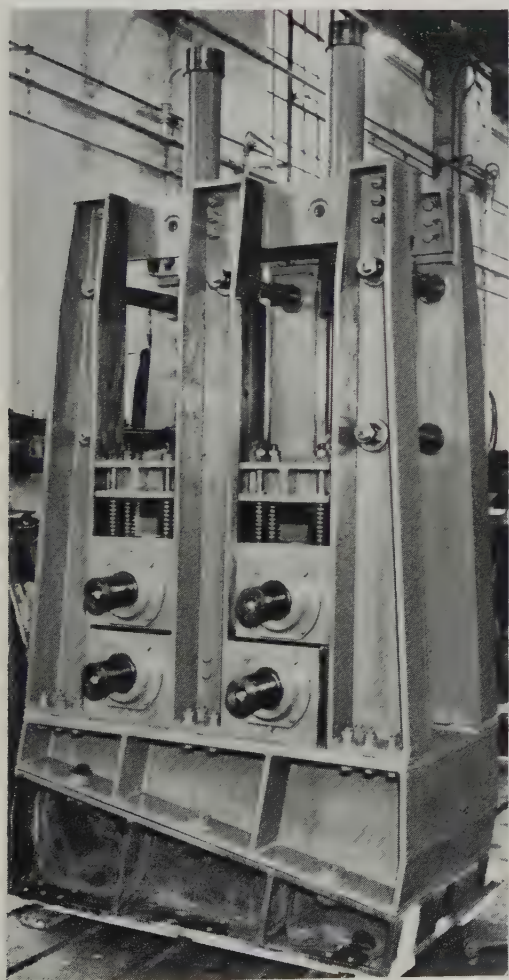
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Recent Special Machines produced include the following for Barrow Steel Works Ltd. Continuous Castings Project.

LEFT: Straightening Rolls, one of four sets supplied.

RIGHT: Cam Oscillating Gear, two of four sets supplied, with Mould Table Units, etc.

LOWER RIGHT: Withdrawal Rolls, one of four sets supplied, complete with Guide and Bending Rolls.



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plastic bonded to steel
has put a new face on

L.D.E.P. CONTROL UNITS



Asked to make this control unit for a new production line, Lancashire Dynamo Electronic Products Ltd., leaders in the field of industrial control equipment, found they were able to imprint instructions on the vinyl by the Maseeley process. Previously they had fitted separate instruction panels after the units had been made.

Because Stelvetite eliminates this, together with need for surface finishing, and can be worked like ordinary sheet steel, L.D.E.P. have decided to use it extensively instead of stove-painted panelling.

This is saving the company production costs and time, in addition to making their units resistant to the difficult corrosive atmospheres encountered in industry.



Plastic
bonded
to
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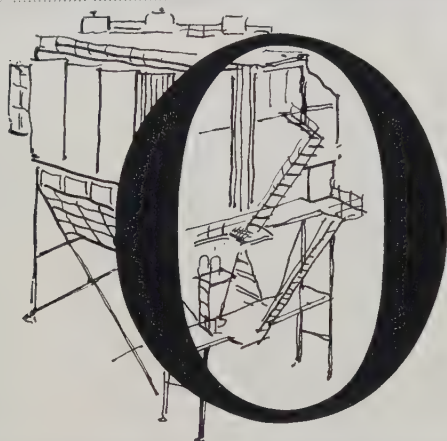
All enquiries about the L.D.E.P. Control Unit should be addressed to Lancashire Dynamo Electronic Products Ltd., Rugeley, Staffs.

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Twenty-three precipitator units at five of Britain's major steelworks – that is the total ordered, so far, from Lodge-Cottrell and Simon-Carves. Six are already on line and another six are scheduled to start up this year.

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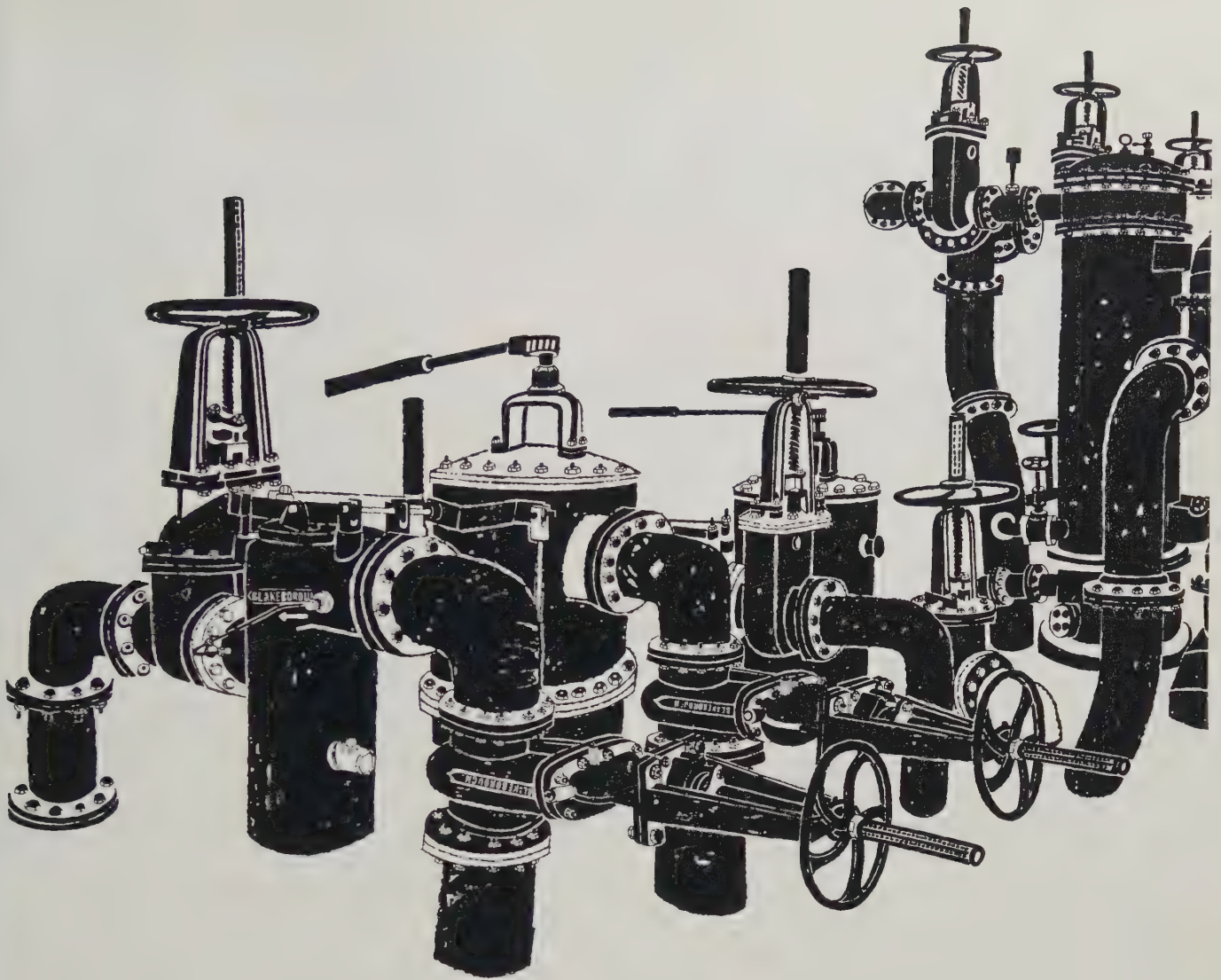
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TAKING POSITIVE ACTION to cut maintenance and lubrication costs, J. Blakeborough & Sons Ltd. world-famous valve manufacturers, consulted the experts—Mobil. After accepting their recommendations, and applying the correct lubrication programme, Blakeborough found that they had made direct savings of over £1,360. Indirect savings were estimated at a further £2,100.

World-wide experience of industrial lubrication

This example of the value of Mobil Economy Service is typical of many that could be cited from almost every industrial area of the world. In all these areas, the world-wide Mobil organization is applying more than 90 years' experience to the cutting of lubrication and maintenance costs.

One plan to meet all lubrication needs

The value of Mobil Economy Service is the value of expert knowledge methodically applied: it is a matter of assessing all the lubrication needs of a business collectively; considering how they can best be met with the fewest different lubricants in the smallest quantities; and making sure that everyone concerned knows how to use the lubricants to the best effect with the absolute minimum of work. The astonishingly large savings that are often achieved are the measure of the experience and skill that Mobil bring to the consideration of every industrial lubrication problem.



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Drive: Chain

Horsepower: 230 h.p.

HEAVY

Weight: 40 tons

Drive: Side rods

Horsepower: 310 h.p.



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Horsepower: 310 h.p.



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Weight: 74 tons

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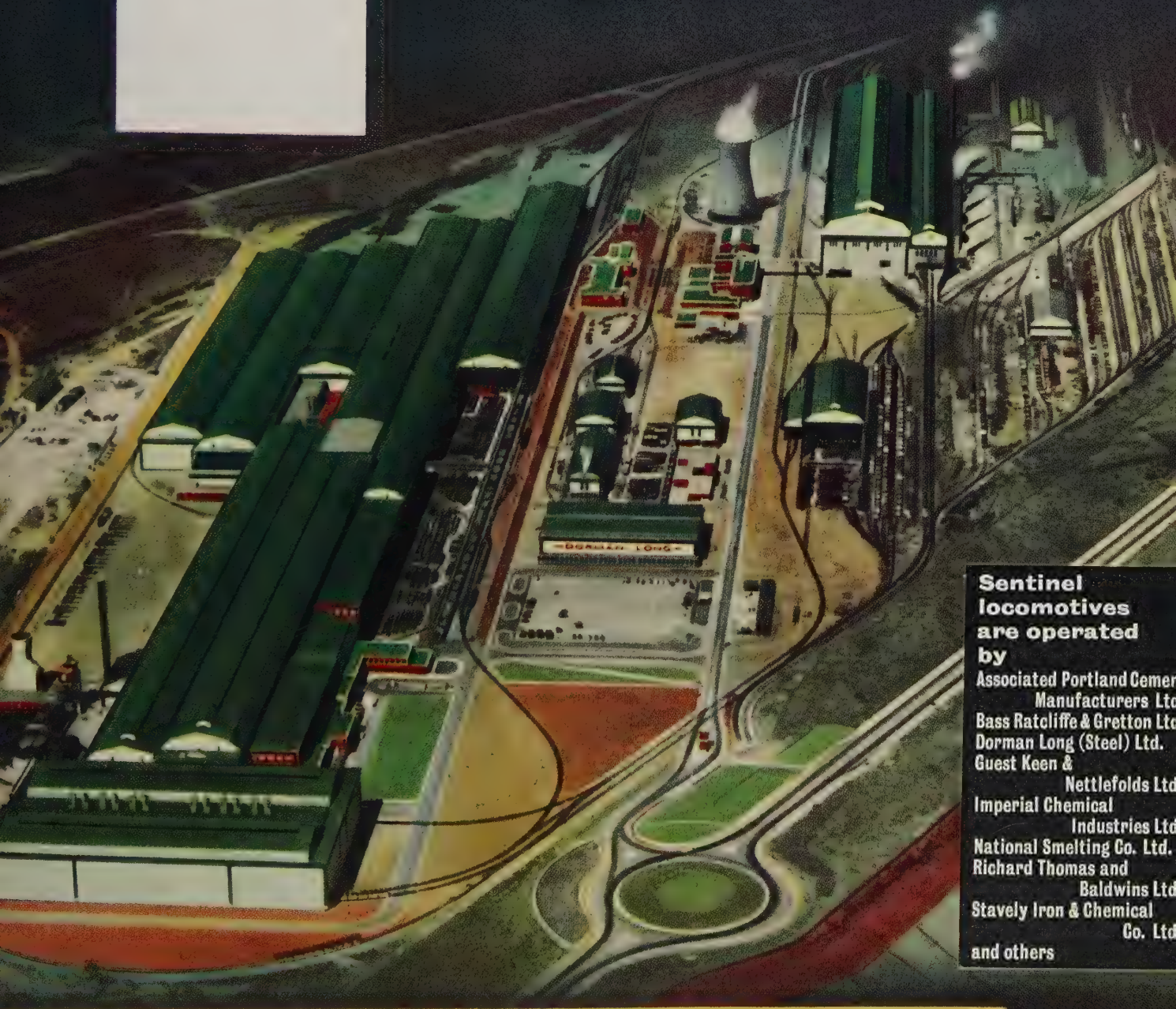
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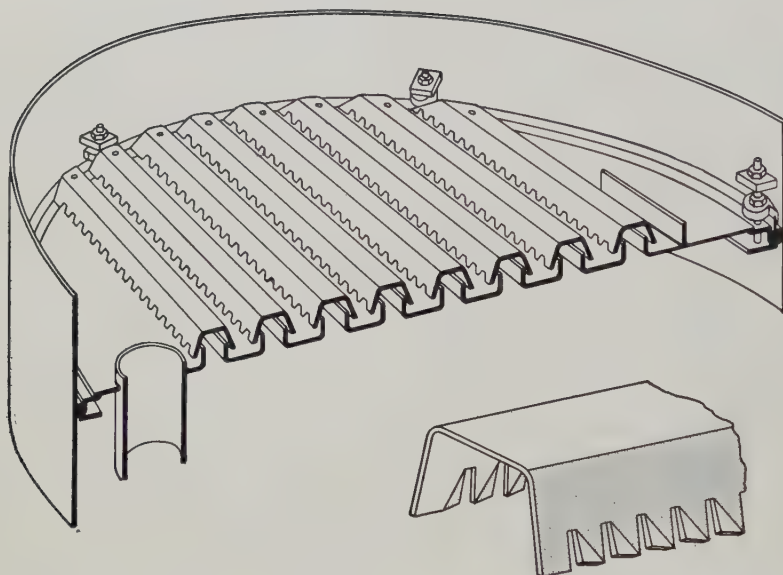
*Aerial photograph of Dorman Long (Steel) Ltd., Lackenby Works,
where a number of Sentinel locomotives are operating.*

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The Coppee Company (Great Britain) Limited not only supply **COPPEE-MONTZ** plates for inclusion in new or existing columns but undertake the design, construction and erection of complete plants for fractionation, distillation, gas scrubbing and other purposes.

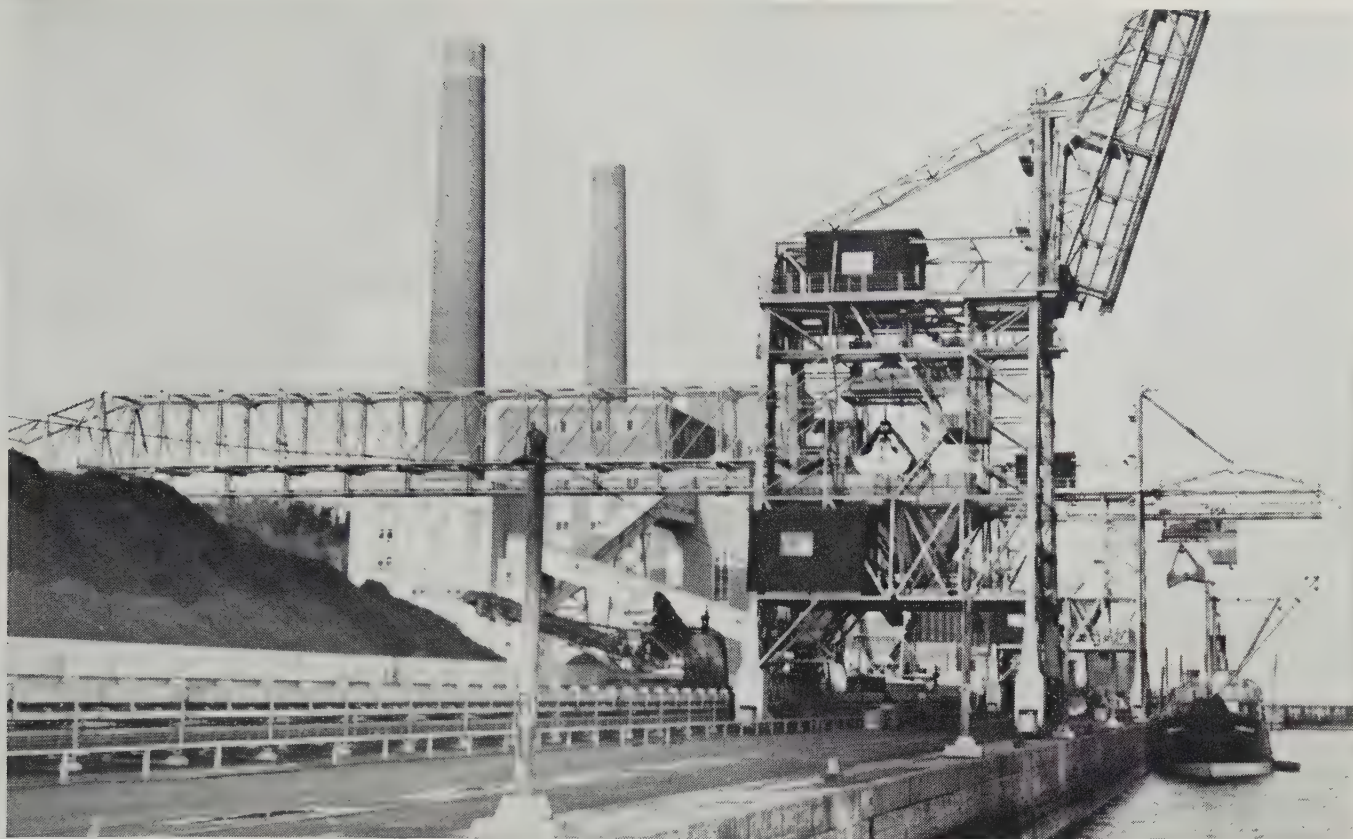
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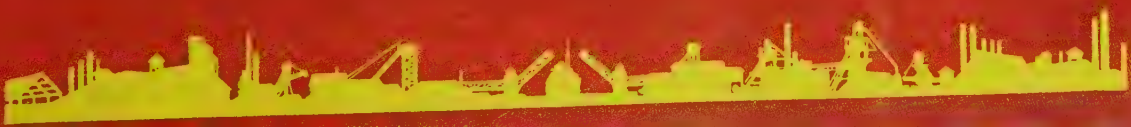
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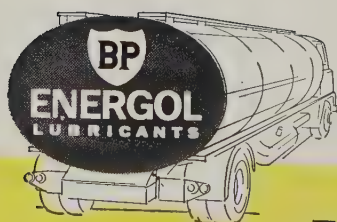


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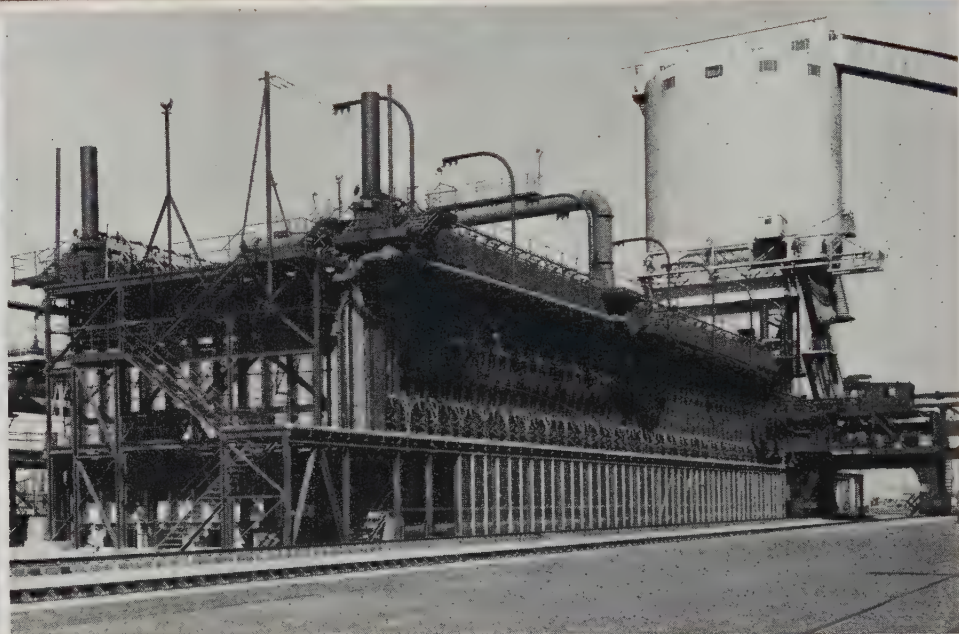
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W. S. WALKER, Ph.D., M.Sc. (Tech.)

WILLIAM SHELLEY WALKER graduated B.Sc.(Tech.) with first-class honours in metallurgy and assaying, from the College of Technology, University of Manchester, in 1933, and in the following year he was awarded his M.Sc.(Tech.) degree. In 1935 he was appointed demonstrator in metallurgy at the university, and in the same year The Iron and Steel Institute awarded him a Carnegie Research Scholarship. For a time he was with the Brown-Firth Research Laboratories under the late Dr W. H. Hatfield before joining the Vitkovice Steel Corporation in Czechoslovakia.

On his return to the UK in 1939 Dr Walker was appointed production manager – light alloys, at Thos. Firth and John Brown. In 1944 he was seconded to the Director of Naval Construction with temporary commission as Lieutenant Commander, RNVR.

Dr Walker rejoined Firth and Brown in 1946, and later that year he was awarded his Ph.D. by Manchester University, for his thesis on thermal analysis. In 1950 he was appointed technical director of the Round Oak Steel Works and in 1957 he became general manager of the company. Dr Walker resigned this post in September 1960 when he joined Campbell, Gifford and Morton Ltd, Consulting Engineers.

Dr Walker was a member of the BISRA Engineering Panel and has been a member of the Steel Making Panel since 1952. He was elected to the Council of BISRA in 1953. In 1955 he was appointed a member of the *ad hoc* committee to advise the Training Committee of the British Iron and Steel Federation on the establishment of management training courses, and in 1958 he was elected a member of the Federation's Steel Producers' Conference.

Dr Walker joined The Iron and Steel Institute in 1935, and became a member of the Committee of the Engineers Group in 1951. In 1960 he was elected an Honorary Member of Council.



W. S. Walker, Ph.D., M.Sc.(Tech.)
Honorary Member of Council

Hot blast stoves

J. Schofield, B.Sc. (Tech.), P. Butterfield, B.A., and P. A. Young, M.A., Ph.D.

INTRODUCTION

HOT BLAST STOVES have received very little attention in the UK and USA scientific and technical press for these past 50 years or so, and one has the impression that, by a process of evolution rather than of design, stoves of great reliability and high thermal efficiency are available, well suited to the needs of modern blast-furnaces. Unfortunately the requirements of the blast-furnace are in the process of drastic modification, largely as a result of charge preparation (sintering and pelletizing) and of blast additions (water vapour, oil, gas, and pulverized fuel). While rule-of-thumb design methods may enable stove design to keep up with slowly evolving blast-furnace techniques, they do not point the way forward to a situation demanding much higher blast temperatures at minimum cost. Hence, during the last two or three years there has been a great deal of interest on the part of stove designers and in more fundamental aspects of the problem. Widely varying methods have been used, varying from more or less classical analyses of heat flow in regenerators to the use of analogue computers. Much of this work is highly complex, and does not commend itself to the attention of the practical operator, and here Voice¹ has done a good service by displaying certain principles with the aid of simple arithmetic.

At some point, however, a more complex analysis of the problem is necessary, and it is the purpose of this paper to present one possible approach, using an analytical theory of heat transfer in regenerators. This latter is so shrouded in mystery and held by many to be so difficult mathematically, that we think it essential to discuss it at the beginning of our paper, rather than to relegate it to an appendix. We shall follow the statement of principles with discussion of actual hot blast stove data, and examine the agreement between theory and practice. Agreement having been established it is then possible to consider the effects of changing operating and stove variables, and to discuss questions of stove optimization.

STOVE THEORY

Heiligenstaedt,² Rummel,³ Schack,⁴ Nusselt,⁵ and others have all developed theories of heat transfer in regenerators and stoves, but a particularly elegant treatment, which has shown itself capable of development over a considerable period of time, is that of

SYNOPSIS

The physical basis of the Hausen regenerator theory is discussed in some detail. Practical measurements have been made on a number of different hot blast stoves, and actual performance is compared with that calculated by the Hausen method. The Hausen theory is then extrapolated so that the influence of such variables as dome temperature, stack temperature, and stove height and dia. may be predicted. Optimum cycle times are discussed, and some comparisons made between three- and four-stove systems.

2018

Hausen.⁶ We have used Hausen's analysis, initially in its earlier, simplified form, and later in the expanded form which makes it possible to calculate both the heat transfer coefficient, and the temperature gradient, in all parts of the stove, even under extreme conditions of construction and operation.

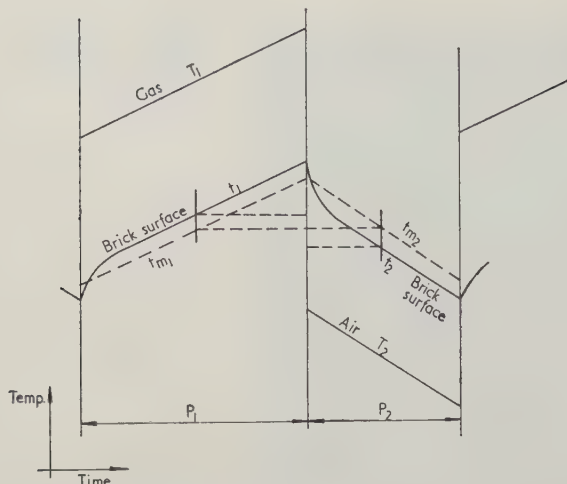
In the following notes we have sought to display the physical basis of the fundamental equation for the overall heat transfer coefficient, and to indicate the refinements introduced by the complete analysis.

In a regenerator the temperature of the gases, as well as the walls, changes with respect both to location and time. Figure 1 shows the temp./time fluctuation of both gases and walls at any given cross-section of the exchanger.

In the heating cycle (duration P_1) the gas temperature, T_1 , is greater than the wall surface temperature, t_1 , and, for the greater part of the cycle, this latter is greater again than the mean brick temperature t_m . (Note that t_m is the mean brick temperature at any moment in time. For *time-means* we shall always use a barred notation; suffix 1 refers to the heating period, and suffix 2 to the cooling period.) Apart from the regenerator ends, the temperature of the hot gases, T , changes almost linearly with time, as does the mean brick temperature t_m ; the surface temperature, t , settles down to a linear rate of change very rapidly after switching. A similar situation applies during the cooling period (length P_2). During the greater part of the heating, on gas, cycle the temperature profile within the wall will be of the form (a) indicated in Fig. 2; during the cooling, on blast, period the profile must be reversed, as at (b), and during the changeover one curve must inflect into the other. For the moment we will assume the essentially linear temp./time distribution illustrated; it can be regarded as empirically determined.

Manuscript received 17 July 1961.

The authors are with the research and development division of Head Wrightson and Co. Ltd.



1 Brick and fluid temperatures at a given section against time

Suppose h_1 is the surface heat transfer coefficient of the gas to the wall. During the heating period both radiation and convection will be appreciable (since we are dealing with the products of combustion) and hence:

$$h_1 = h_{c1} + h_{r1}$$

The total quantity of heat transferred during time P_1 can then be written:

$$Q_{P1} = h_1 A (T_1 - \bar{t}_1) P_1$$

or

$$(\bar{T}_1 - \bar{t}_1) = Q_{P1} / A h_1 P_1 \quad \dots\dots\dots (1)$$

where A is the brick area, and time-mean values of temperatures are used.

During the period on blast, assuming that the stove has settled down to an equilibrium state over many cycles, and that the bank, as it were, is not being robbed, we can write a similar expression for Q_{P2} :

$$Q_{P2} = h_2 A (\bar{t}_2 - T_2) P_2$$

or

$$(\bar{t}_2 - T_2) = Q_{P2} / A h_2 P_2 \quad \dots\dots\dots (2)$$

Here h_2 (brick-to-air) is essentially a convective coefficient.

We must now seek to eliminate the surface temperature t from these equations. Consider a plane wall without heat sources; the classical heat conduction equation is as follows:

$$\frac{\partial t}{\partial P} = \alpha \frac{\partial^2 t}{\partial x^2} \quad \dots\dots\dots (3)$$

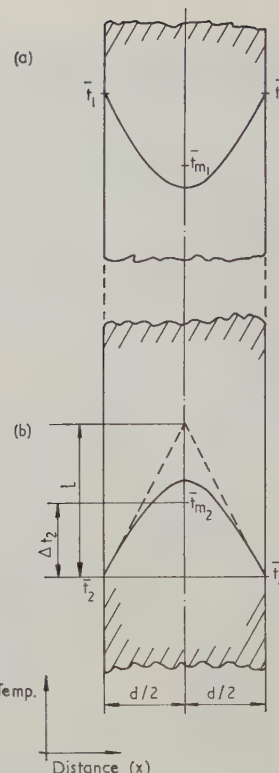
where P is time, x refers to the x -coordinate, and α is the thermal diffusivity of the material ($k/c\rho$, where k is the conductivity, c the specific heat, and ρ the density).

If the temp./time relationship is linear, then $\partial t / \partial P = \text{constant}$; therefore

$$\alpha \partial^2 t / \partial x^2 = \text{constant}$$

and a double integration will lead to a parabola, as previously assumed. Thus the assumption of a linear temp./time relationship leads to a parabolic temp./distance profile within the brick; this basic assumption of the method may be shown, experimentally, to hold for the greater part of either cycle.

Referring to Fig. 2b, the quantity of heat transferred from the interior of the brick to the wall must equal the heat passing by convection to the blast:



a Heating, on gas

b Cooling, on blast

2 Temperature gradients within the brick at any given time

$$Q_{P2} / P_2 = -k A (\partial t / \partial x)_{x=0}$$

also

$$= (d/2) (\partial t / \partial x)_0 = (Q_{P2} / A) (d / 2k P_2)$$

The geometry of the parabola is such that the height of the parabola is $\frac{1}{2}l$, and the distance Δt_2 (equal to the mean height \bar{t}_{m2}) is two-thirds the height of the parabola. Therefore

$$(\bar{t}_{m2} - \bar{t}_2) = (Q_{P2} / A) (d / 6k P_2)$$

Similarly for heating on gas:

$$(\bar{t}_1 - \bar{t}_{m1}) = (Q_{P1} / A) (d / 6k P_1)$$

and since $\bar{t}_{m1} = \bar{t}_{m2}$ and $Q_{P1} = Q_{P2} = Q_P$

$$\text{then } (\bar{t}_1 - \bar{t}_2) = \frac{Q_P}{A} \left\{ \frac{1}{P_1} + \frac{1}{P_2} \right\} \frac{d}{6k} \quad \dots\dots\dots (4)$$

Adding equations (1), (2), and (4) we have:

$$(T_1 - T_2) = \frac{Q_P}{A} \left[\frac{1}{h_1 P_1} + \frac{1}{h_2 P_2} + \frac{d}{6k} \left\{ \frac{1}{P_1} + \frac{1}{P_2} \right\} \right]$$

$$\text{or } Q_P = \frac{A}{(1/h_1 P_1 + 1/h_2 P_2 + d/6k(1/P_1 + 1/P_2))} (T_1 - T_2) \quad \dots\dots (5)$$

Here Q_P is the total heat transferred per cycle (in time $(P_1 + P_2)$) and hence the heat flow per unit time is:

$$q = \frac{A (T_1 - T_2)}{\{1/h_1 P_1 + 1/h_2 P_2 + d(1/P_1 + 1/P_2)/6k\} (P_1 + P_2)} \quad \dots\dots\dots (6)$$

This is now in the standard form: $Q = AU' \Delta T$ where U' is an overall heat transfer coefficient:

$$1/U' = [1/h_1 P_1 + 1/h_2 P_2 + d(1/P_1 + 1/P_2)/6k] (P_1 + P_2) \quad \dots\dots (7)$$

Equation (5) has been deduced only for a cross-section of the stove, and for the total regenerator the logarithmic mean temperature difference (LMTD) between the ingoing and outgoing gases must be used.

TABLE I Symbols used in text

Symbol	Meaning	Unit
P	Period	h
T	Fluid temperature	°F
Q	Quantity of heat transferred	Btu
A	Heating surface area	ft ²
U	Overall coefficient of heat transfer	Btu/h ft ² °F
V	Fluid velocity at standard conditions of temp. and pressure	ft/s
W	Heat capacity of fluid/unit time	Btu/h °F
M	Total mass of checker brickwork	lb
t	Brick temperature	°F
h	Heat transfer coefficient	Btu/h ft ² °F
q	Rate of heat transfer	Btu/h
k	Thermal conductivity of brick	Btu/h ft ² °F/in
c	Specific heat of brick	Btu/lb °F
d	Brick thickness	in
Δt	Logarithmic mean temperature difference	°F
ρ	Density of brick	lb/ft ³
α	Thermal diffusivity	in ² /h
ϕ	A factor to allow for the rapid temp. variations following the reversing operations	Dimensionless
η	Efficiency of a regenerator	Dimensionless
λ	Reduced regenerator length	Dimensionless
Π	Reduced regenerator period	Dimensionless
δ	Equivalent diameter of checker hole	in
Suffixes		
1	Value during gas (or heating) period	
2	Value during blast (or cooling) period	
m	Mean value with respect to position	
c	Convection	
r	Radiation	
bar over		
character	Indicates time-mean values	

If the heating and cooling periods are equal ($P_1 = P_2 = P$) then we may rewrite equation (6):

$$q = Q_P/2P = \frac{A}{2(1/h_1 + 1/h_2 + d/3k)}(T_1 - T_2) \dots\dots\dots(8)$$

Consider now two fluid streams flowing on opposite sides of a plane wall of area A' , thickness x , and thermal conductivity k : i.e. the simplest possible recuperator. If h_1 and h_2 are the gas/wall and wall/gas coefficients, and the higher temperature gas is at temperature T_1 and the lower temperature gas at T_2 , we have:

$$q = \frac{A'}{(1/h_1 + 1/h_2 + x/k)}(T_1 - T_2) \dots\dots\dots(9)$$

For the assumptions considered the regenerator is, then, formally equivalent to a recuperator with one-third the regenerator wall thickness, bearing in mind that, in the regenerator, heat flows in to and out of *both* walls (i.e. $A = 2A'$). This equivalence has proved a stumbling block to some who have assumed that the theory depends on the recognition of an analogy between regenerator and recuperator. The equivalence is merely formal; it is difficult to see it physically. At the same time the existence of a precise mathematical equivalence makes it easy to accept the use of an LMTD driving force, by analogy with the recuperator.

The basic assumption in equation (7) is the linear gas temp./time relationship (or the equivalent parabolic brick profile), and for many purposes equation (7) is sufficiently accurate. The stove or regenerator is only one case of the generalized packed bed problem, and here it can be shown⁷ quite generally that the temp./position relationship for any point within the sphere or tile or other solid body can be expressed as a power series in x^2, x^4, \dots . Neglecting powers higher than the quadratic, a very much simplified solution to the overall problem is forthcoming. However, the basic equations may be solved without this simplifying

assumption, using numerical methods programmed for a computer, and the errors involved in the simple method are usually extremely small.

Expanded theory

While the time gradient of t_m is almost linear for a large part of the regenerator, it is otherwise at the ends of the regenerator, and we have already stressed that the brick surface temperatures are not linear with respect to time immediately after changeover. To analyse these effects fully it is necessary to regard the stove as being in a state of forced oscillation (like the vibrations of a string) and to split the oscillations into a fundamental and higher harmonics. If this is done it is found that the exact calculation of the fundamental oscillation takes the transient changes after reversal fully into account. To account for the effects at the ends of the stove higher harmonics must be evaluated.

Three simultaneous differential equations may be set up: the classical heat conductivity equation for the brick (equation (3)) and two equations describing the transfer of heat from the hot gas to the brick surface, and hence into the brick (or *vice versa* for the on-blast period). It is also necessary to postulate that at the end of each full cycle ($P_1 + P_2$) all brick temperatures are unchanged; and it is found that there are an infinitely greater number of solutions satisfying this condition. These solutions are called 'Eigen-functions' and are characterized by Eigen-values, λ , comprising all integers from 0 to ∞ .

The fundamental oscillation: Eigen-function of zero order

It may be shown that the zero order Eigen-function ($\lambda=0$) corresponds to the fundamental oscillation, and that it gives a temperature gradient along the length of the stove precisely the same as that obtaining in a continuously operating recuperator. In this solution the average brick temperature t_m is linear with respect to time (so that the ends of the regenerator are not fully covered), but deviations of the brick temperature profile from a parabola, after changeover, are completely described. What is more, the expression for the heat transfer coefficient is almost unchanged; it is merely necessary to multiply the term $d(1/P_1 + 1/P_2)/6k$ by a factor ϕ :

$$\text{when } d^2(1/P_1 + 1/P_2)/2\alpha \leq 10 \\ \text{then } \phi = 1 - d^2(1/P_1 + 1/P_2)/60\alpha \dots\dots\dots(10)$$

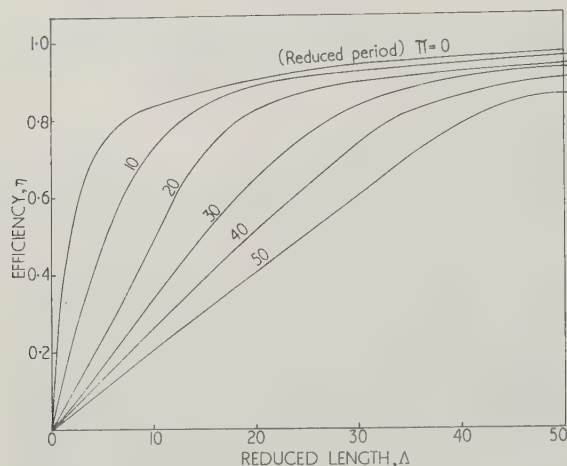
$$\text{and when } d^2(1/P_1 - 1/P_2)/2\alpha \geq 10 \\ \text{then } \phi = 2 \cdot 142 / (0 \cdot 3 + d^2(1/P_1 + 1/P_2)/2\alpha)^{-\frac{1}{2}} \dots\dots\dots(11)$$

For very thin bricks $\phi \rightarrow 1$ and equation (7) then holds accurately within the scope of the zero order Eigen-function. For thick bricks ϕ also tends to a constant value and the heat transfer coefficient becomes independent of brick thickness.

Experiments show that these expressions describe actual conditions exactly, within the limits of experimental accuracy, and within the region where $\lambda=0$ applies.

End effects: Eigen-functions of higher orders

We have assumed that, within the stove, gas temperatures vary linearly with time. But the temperature at which the hot and cold gases enter the regenerator should remain constant, and the zero order Eigen-function can neither represent this condition, nor any bends in the t_{m1} or t_{m2} curves.



3 Efficiency η of a regenerator in relation to the reduced length Δ and reduced period Π

It is possible to develop the gas temperature T as an infinite series, involving all the Eigen-functions, and if we impose the condition T (entry)=constant, it is necessary to use a number of these terms to achieve any kind of approximation to constancy. By summing all the terms it is possible to impose the entry conditions, and to account for the t_m deviations. With very short regenerators, or short cycle times, the influence of these higher order functions moves into the interior, which is normally controlled by the zero order function only.

The calculation of the heat transfer coefficient with higher order Eigen-values is very complex, and it is possible here only to give a glimpse of the reasoning behind it.

Hausen shows that it is possible, mathematically, to regard the brick, in any given section of the regenerator, as uniform in temperature t_m , so that the driving force is $(T_1 - t_1) = (T_1 - t_{m1})$, or rather, the mean value $(T_1 - t_{m1})_M$ with respect to time. To achieve this simplification a corrected heat transfer coefficient must be used, related to the brick temperature:

$$q_p = Q_p/A = h^*_1(T_1 - t_{m1})_M P_1 \dots (12)$$

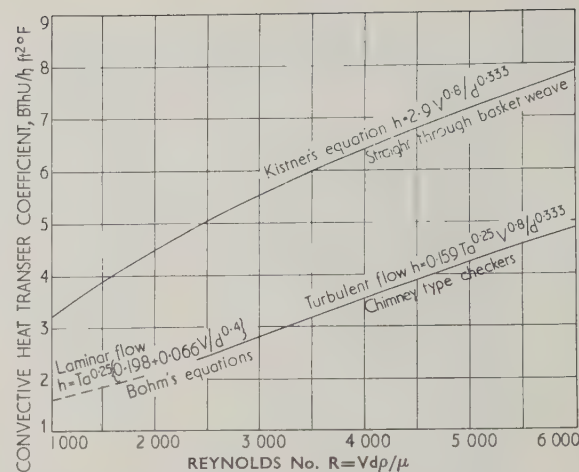
$$\text{where } 1/h^*_1 = \frac{1}{h_1} + \frac{\phi d}{6k} \dots (13)$$

In the zero order case the mean temperatures of the brick t_m are the same at corresponding points in time of the heating and cooling cycles; but in higher order cases there are lags, and consequent hysteresis loops between t_{m1} and t_{m2} at the ends of the regenerators. From equation (12) we see that in the heating period heat transfer is controlled by $(T_1 - t_{m1})_M$ (if we use an appropriately converted value of h_1), and during cooling $(t_{m2} - T_2)_M$ is the driving force. But for zero order Eigen-functions, $t_{m1} = t_{m2}$ at the middle of the period (see Fig.1) and hence:

$$(T_1 - t_{m1}) + (t_{m2} - T_2) = (T_1 - T_2)$$

Hence, in this case, the total available temperature difference between hot and cold gases is used in the middle of the heat transfer period. At any point where a hysteresis loop occurs the value of $(T_1 - T_2)$ is reduced by an amount equal to the time-mean height of the loop, i.e. by $(t_{m1} - t_{m2})_M$.

Thus the heat transfer is correspondingly reduced,



4 Plot showing a comparison between Kistner's and Bohm's equations for convective heat transfer coefficients in checker brickwork (2in square channel, air temp. 600°C)

in the ratio η of the amount of heat actually transferred to that which would be transferred in an ideal exchanger defined by the dimensionless factor:

$$\Delta = hA/W \quad (= \infty \text{ for an ideal exchanger})$$

where W is the heat capacity of the gas flowing per unit time. Δ is called the 'reduced length', since an actual exchanger is only as efficient as a shorter ideal unit.

Cycle time must obviously affect the hysteresis loops, and another dimensionless term called the 'reduced period' is introduced:

$$\Pi = 2hP_1/\rho cd$$

This term arises in the basic differential equations of the system.

In Fig.3 the efficiency is plotted as a function of Δ and Π . The efficiency increases as Π decreases (i.e. with shorter cycles), for any given value of Δ . With the zero order Eigen-function when $\Pi = 0$ the efficiency becomes equal to that of a recuperator with the same value of Δ .

Let us write the overall heat transfer coefficient for the zero order Eigen-function as U_0 :

$$\frac{1}{U_0} = [1/h_1 P_1 + 1/h_2 P_2 + \phi d(1/P_1 + 1/P_2)/6k](P_1 + P_2) \dots (14)$$

For the general case, whether $W_1 P_1 = W_2 P_2$ or not, we may rewrite Δ and Π :

$$\Delta = \frac{4U_0(P_1 + P_2)A}{W_1 P_1 + W_2 P_2} \dots (15)$$

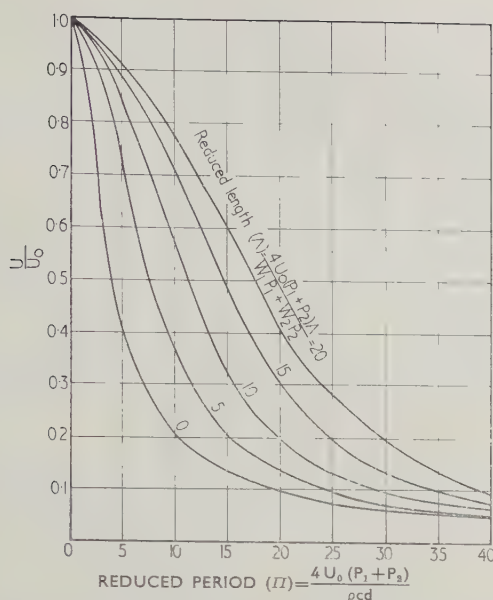
and

$$\Pi = \frac{4U_0(P_1 + P_2)}{\rho cd} \dots (16)$$

If U is our required overall heat transfer coefficient for higher order Eigen-functions, then it is possible to relate U/U_0 to Δ and Π , as in Fig.5. Here Π is expressed in terms of stove area A and mass of brick M for practical convenience:

$$\rho d/2 \simeq M/A$$

We have, then, shown how to calculate the overall heat transfer coefficient for the zero order Eigen-function, and how to correct it for higher orders, thus allowing for end effects. We shall now apply these methods of calculation to actual stove problems.



5 Relation between true heat transfer coefficient U and U_0 , from the Eigen-function of zero order

Choice of heat transfer coefficients

All regenerator theories involve a knowledge of the heat transfer coefficients in the brick checkers. Equation (14) shows how the overall heat transfer coefficient between gas and blast is dependent on the individual heat transfer coefficients h_1 and h_2 for the gas and blast periods respectively. The accuracy of the regenerator theory is thus largely determined by the choice of heat transfer coefficients.

During the blast cycle where radiation from the checkers to the blast is unimportant, heat transfer occurs by convection, but during the gas period, where a substantial partial pressure of carbon dioxide and to a lesser extent water vapour exists, radiation and convection from the gas to the checkers are both important mechanisms of heat transfer. The radiation coefficient is accurately estimated from Hottel charts, providing the partial pressures of carbon dioxide and water vapour and the beam length are known. Convection coefficients, however, are less accurately known, but Kistner⁸ and later Bohm⁹ conducted experimental work some 30 years ago to determine convective heat-transfer coefficients in checker brick-work.

Kistner investigated heat transfer and pressure drop in an experimental basket-weave checker both of the straight-through and double-staggered arrangements. Duct sizes varied from 1.2 up to 3.72 in square. He predicted convective heat transfer coefficients, both for the heating and cooling periods, as

$$\text{for straight-through basket weave } h = 2.9 \frac{V^{0.5}}{\delta^{0.333}}$$

$$\text{and for double-staggered checkers } h = 3.25 \frac{V^{0.5}}{\delta^{0.333}}$$

Both equations are valid at a temperature of 600°C. The effect of temperature on the coefficient is obtained by increasing the calculated value by 1% for every 30°C above 600°C, and by decreasing it by the same amount for temperatures below 600°C. Kistner found that the equations were equally valid for both laminar and turbulent flow.

Bohm investigated convective heat transfer coefficients in chimney type checkers in 13 ft long single ducts. The duct width was varied between 1.62 in to 3.48 in and velocities varied between 1 ft/s to 23 ft/s. He obtained different equations for the laminar and turbulent regions and included a temperature term in his equations. Bohm gave the convective heat transfer coefficients for smooth chimney type checkers as

$$\text{for laminar flow } h = T_a^{0.25} \left\{ 0.198 + \frac{0.066 V}{\delta^{0.4}} \right\} \quad (17)$$

$$\text{and for turbulent flow } h = \frac{0.159 T_a^{0.25} V^{0.8}}{\delta^{0.333}} \quad (18)$$

Neither equation was applicable to the transition region and Bohm suggested that the coefficients over this Reynolds number range be obtained by plotting the laminar and turbulent equations and interpolating between the two lines obtained. Bohm also investigated the effect of artificial roughness on the heat transfer coefficient and found that the use of serrated surfaces gave a twofold enhancement of the coefficient in the turbulent region.

A comparison of the coefficients obtained, using Kistner's and Bohm's equations for a fluid temperature of 600°C and a duct size of 2 in, is given in Fig. 4.

The present authors are investigating heat transfer coefficients in long square-section ducts fabricated from mild steel and having a thin internal coating of alumina to simulate the effect of the roughness of the checker bricks. This channel is surrounded by a steam jacket so that heat transfer measurements can be made in the 'steady' state. Since the heat transfer coefficient on the steam side is several hundred times that on the gas side, the overall heat transfer coefficient obtained in the tests approximates very nearly to the individual coefficient on the gas side.

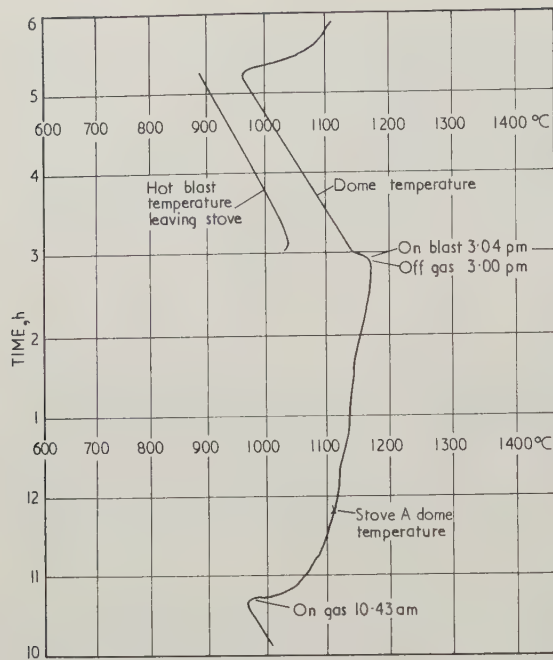
Preliminary results on a 4 in square section with air on the gas side indicate fairly close agreement with coefficients predicted from Bohm's equation. Later experiments with hydrogen on the gas side will enable natural convection effects at high temperature (i.e. the Grashof number) to be simulated.

CORRELATION OF ACTUAL STOVE PERFORMANCE WITH THAT PREDICTED FROM REGENERATOR THEORY

In order to examine the validity of Hausen's regenerator theory a number of tests on hot blast stoves at various iron plants have been undertaken. Basic measurements of air and gas flow rates, and such temperatures as are accessible, have been recorded and these measurements used in the regenerator theory to calculate the heat transfer from hot gas to blast air. The stove duty calculated from a knowledge of blowing rate and hot blast temperature has then been compared with the value calculated from the regenerator theory. If the theory can be substantiated from practical tests, the effect of changes of operating conditions on stove performance can be assessed. The use of the regenerator theory in the thermal design of stoves will also represent an advance over most design methods in use today.

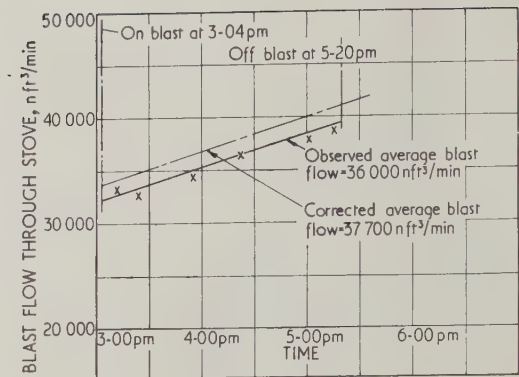
Method of calculation

We have thought it useful to set out one complete calculation in detail:



6 Record of dome temperature and hot blast temperature leaving the stove

- (i) determine the average rate of blast-furnace gas flow to the stove
- (ii) determine the average blast flow through the stove; this is best obtained by traversing the cold blast main just before the stove, or, more indirectly, the supplementary cold blast main. In the latter case use is made of the record of the total blast volume to the furnace
- (iii) if a record is available of the blast temperature leaving the stove before mixing with cold by-pass air, then it is possible to check the accuracy of the velocity traverse in the cold blast main. In most cases, however, it is necessary to use the blast flow through the stove to calculate the blast temperature leaving
- (iv) from the blast-furnace gas analysis and time-mean waste gas analysis, determine the volume of products of combustion and flame temperature
- (v) calculate the time-mean inlet gas temperature to the top of the checkers from consideration of the heat transfer from the gas to the combustion chamber
- (vi) construct a heat balance between gas and blast in order to determine the blast time required to extract the heat transferred from the gas to the checker mass during the heating period. The calculated blast period may not necessarily coincide with the blast time actually employed in the test, but a balance is necessary to satisfy an essential condition of Hausen's equation (i.e. that 'the bank is not robbed')
- (vii) calculate the heat transfer coefficients for the gas and blast periods
- (viii) calculate the overall heat transfer coefficient between gas and blast and make the necessary Hausen *A* and *II* corrections according to Fig.5



7 Plot of blast flow through Stove A against time

- (ix) determine the logarithmic mean temperature difference between gas and blast
- (x) compute the heat transferred/cycle from

$$Q = P_T U A \Delta T_m \dots \dots \dots (19)$$
 where $P_T = P_1 + P_2 + \text{changeover time}$
- (xi) compare the value obtained in (x) above with the actual stove performance calculated from the blast volume and temperature.

Data used in the calculations (see Table II)

A summary of the measurements taken during this particular test stove is given in Table III. (Other stove tests have varied in detail according to mode of instrumentation, and the possibility or otherwise of installing additional measuring equipment.)

Calculation

(i) Average rate of flow of blast-furnace gas to stove (Table III) 574 000 n ft³/h.

(ii) Average blast flow through stove During the blast period the cold blast main was traversed at regular time intervals with a Stauscheibe tube (Fig.7, full line).

(iii) (a) Temperature drop of hot blast between stove and blast-furnace A calculation of the heat lost from the hot blast main between the stove and the blast furnace shows that the temperature drop of the hot blast is 5°C.

The mixed blast temperature, at the point where hot blast from the stove meets the supplementary cold blast, is thus 875°C, i.e. 5°C above the blast temperature recorded in the bustle main.

(iii) (b) Check on accuracy of Stauscheibe traverse in cold blast main The 'time-mean' blast flow through the stove derived from Fig.7 can now be checked by writing a heat balance at the point where the cold supplementary blast meets the hot blast from the stove.

A continuous record of blast temperature leaving the stove before the mixer valve gave a time-mean temperature of 972°C over the blast period.

The total blast volume to the furnace is 42 500 n ft³/min at a temperature of 875°C and the supplementary air has a temperature of 43°C.

Heat in blast at 875°C above 0°C = 32.75 Btu/std ft³.

Heat in cold blast at 43°C above 0°C = 0.15 Btu/std ft³.

Heat in blast at 972°C above 0°C = 36.85 Btu/std ft³.

Working above 43°C, the cold blast temperature, we have:

heat in total blast at 875°C = heat in blast leaving stove at 972°C.

TABLE II Details of the checker filling and combustion chamber (Stove A)

Checkers Property	Combustion chamber Property		
Type	McKee (with cross flues)	Shape	Circular
Height	80.75 ft	Diameter	6.33 ft
Weight	730.2 tons	Height	87.50 ft
Equivalent dia. of checker hole	1.938 in (1 $\frac{1}{8}$ in ²)	Cross-sectional area	31.52 ft ²
Total checker free flow area	97.43 ft ²	Heating surface area	1 600 ft ²
Free area/hole	3.70 in	Soldier wall inside combustion chamber	
Checker thickness	1.25 in	Diameter	5.83 ft
Checker heating surface area	186 810 ft ²	Height	60.00 ft
Cross flues	16 000 ft ²	Cross-sectional area	24.47 ft ²

If x = mean blast flow through stove over the blast period (n ft³/min) then

$$42500 (32.75 - 0.15) = (36.85 - 0.15)x$$

giving $x = 37700$ n ft³/min.

This value compares with an average blast flow through the stove of 36000 n ft³/min obtained from the velocity traverse in the cold blast main; from other considerations the higher value is thought to be the more accurate. The dotted line in Fig.7 shows the corrected blast flow rate through the stove.

(iv) (a) *Combustion of blast-furnace gas* From the blast-furnace gas analysis, the theoretical products of combustion are calculated as follows:

	Vol./vol. of BF gas
CO ₂	0.4202
H ₂ O (vap.)	0.0636
N ₂	1.2087

The average waste gas analysis gave a carbon dioxide content of 23.47% in the dry gases. A carbon dioxide balance gives the excess air as 0.163 vol./vol. of blast-furnace gas.

The actual products of combustion are:

	Vol./vol. of BF gas
CO ₂	0.4202 = 22.65%
H ₂ O (vap.)	0.0636 = 3.43%
N ₂	1.2087 = 65.13%
Excess air	0.1630 = 8.79%
	1.8555 = 100.0%

(iv) (b) *Calculation of gas temperature entering combustion chamber after combustion of blast-furnace gas* The gas temperature after combustion of the blast-furnace gas is calculated from a heat balance.

Calorific heat of blast-furnace gas + sensible heat in blast-furnace gas and combustion air = sensible heat in products of combustion.

The gas temperature obtained from this calculation is 1380°C.

(v) *Gas temperature entering checkers* The gases transfer heat to the combustion chamber during the gas period so that the gas temperature entering the top checkers will be lower than that obtained from combustion of the blast-furnace gas.

Assume a gas temperature entering the top of the checkers and calculate the emissivity and absorptivity of the gases by Hottel charts.

Next determine the 'time-mean' combustion wall temperature during the gas period assuming that the dome temperature and temperature recorded by the

TABLE III Measurements taken during test

Measurement	How taken	Value
Average blast-furnace gas flow-rate	Orifice plate	574 000 n ft ³ /h
Time on gas		4.284 h
Blast-furnace gas analysis	Orsat	CO ₂ = 12.50% H ₂ = 1.17% N ₂ = 54.56% CO = 28.05% CH ₄ = 1.47% H ₂ O = 2.25%
Net calorific value	Calculated from gas analysis	111.5 Btu/standard ft ³
Average waste gas analysis	Orsat	CO ₂ = 23.47% in dry gas
Average blast volume to furnace	Venturi at turbo-blower inlet	42 500 n ft ³ /min
Average blast flow through stove	Velocity traverse with Stauscheibe tube	37 900 n ft ³ /min
Cold blast temp.	Mercury in glass thermometer	43°C
Hot blast temp. at furnace	Thermocouple in bustle main	870°C
Steam addition to blast	Orifice plate	733 lb/h
Average stack temp.	Thermocouple	150°C
Hot blast temp. leaving stove	Thermocouple	See Fig.6

thermocouple at the bottom of the combustion chamber are constant. Measure the brick temperature at the end of the blast and beginning of the gas periods. Now calculate the radiation coefficient from gas to combustion wall surface and the temperature difference between gas and surface. The heat transferred from the hot gases to the combustion chamber can now be calculated from the usual equation:

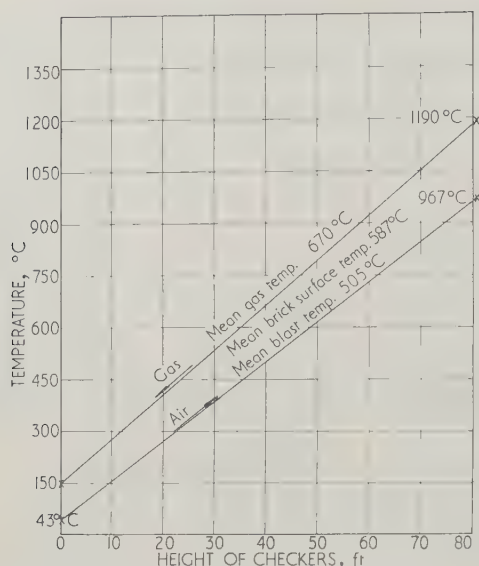
$$q = h_r \cdot A_c \cdot \Delta t_m$$

The value obtained should be equal to the sensible heat lost by the gases to the combustion chamber. If the two values do not agree continue by iteration.

For the example chosen, the time-mean gas temperature entering the checkers is 1190°C. This value is 65°C above that given by the dome temperature record (Fig.6) and this seems reasonable since the dome thermocouple will probably read a temperature intermediate between gas and brick. On the other hand the difference between 1190°C and the adiabatic flame temperature (1380°C) seems excessive. In the present instance the analysis of blast-furnace gas, particularly with regard to methane, was suspect, and hence the calculated calorific value may well be in error. At the same time it may be noted that the heat transferred to the walls during the gas period is greater than the transfer from the walls on blast, and the difference may be accounted for in part by heat losses from the stove surface to the surroundings. Difficulties of this kind can only be resolved by accurate measurement with suction pyrometers.

(vi) *Blast time required to obtain a heat balance over the checkers* A heat balance between gas and blast over the checkers gives the blast time.

Heat in blast at 875°C, Btu/ft ³	= 32.75
Heat in blast at 43°C, Btu/ft ³	= 0.15
Blast volume, n ft ³ /min	= 42 500
Heat in products of combustion at 1190°C, Btu/ft ³ BF gas	= 96.7
Heat in products of combustion at 150°C, Btu/ft ³ BF gas	= 10.6
Time on gas, h	= 4.284
Gas rate, n ft ³ /h	= 574 000



8 Time-mean gas and air temperature distribution in checkers during a cycle, Stove A

Heat in steam addition to blast,
Btu/h $= 0.47 \times 10^6$

If P_2 = time on blast, a heat balance reads

$$(42500 \times 60) (32.75 - 0.15) P_2 + 0.47 \times 10^6 P_2 = (574000 \times 4.284) (96.7 - 10.6)$$

giving $P_2 = 2.53$ h.

The actual blast time employed during the test was 2.33 h (Fig. 6). This result indicates that the stove should have continued on blast for a further 12 min so that all the heat transferred to the checkers during the gas period might be transferred to the blast. The time-mean blast temperature of 976°C leaving the stove is therefore determined from Fig. 6 by extrapolating the temperature record by 12 min. Time-mean temperatures are plotted against checker height in Fig. 8.

By extrapolating the corrected blast flow through the stove (Fig. 7) to cover a blast period of 2.53 h, the average blast flow through the stove is now seen to be 37900 n ft³/min.

(vii) Calculation of heat transfer coefficients in the checkers

(a) Gas cycle

V_1 = Gas velocity in checkers (corrected to 0°C)
 $= 2.87$ ft/s

Mean gas temperature over checkers = 670°C = 943°K (Fig. 8)

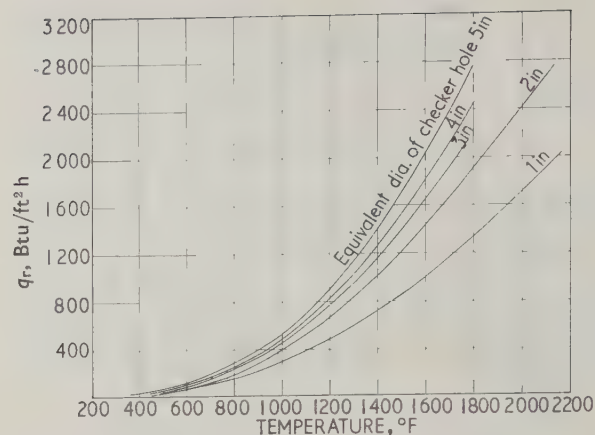
Equivalent checker diameter = 1.938 in.

The flow is laminar, so, using Bohm's coefficient (equation (17))

$$h_{c1} = 1.91 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

The radiation coefficient, h_{r1} , must be added to this value to obtain the total heat transfer coefficient from gas to checkers. This radiation coefficient is obtained by reading the heat transfer rate from Fig. 9 at both the mean gas and mean brick temperature and dividing the result by the temperature difference between the gas and brick obtained from Fig. 8.

From Fig. 9, q_r at a mean gas temperature of 670°C (1237°F) and an equivalent checker dia. of 1.938 in is 740 Btu/ft² h, and q_r at a mean brick temperature of



9 Plot of rate of heat transfer by radiation against temperature ($\text{CO}_2 = 23\%$; $\text{H}_2\text{O} = 1\%$)

587°C (1090°F) = 500 Btu/ft² h. Thus the radiation coefficient from gas to checkers

$$= \frac{740 - 500}{1237 - 1090} = 1.63 \text{ Btu/ft}^2 \text{ h } ^\circ\text{F}$$

The combined radiative and convective heat transfer coefficient is

$$h_1 = h_{c1} + h_{r1} = 3.54 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

(b) Blast cycle

V_2 = Blast velocity in checkers (corrected to 0°C)

$$= 6.13 \text{ ft/s}$$

Using Bohm's equation for turbulent flow (equation (18)) and a mean blast temperature over checkers of 505°C (Fig. 8):

$$h_2 = 2.88 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

(viii) Overall heat transfer coefficient between gas and blast The overall coefficient between gas and blast is given by equation (19) and the ϕ factor by equation (10). Thermal diffusivity of brick at a mean temperature of 587°C = 1.445 in²/h

Brick thickness = 1.25 in; therefore $\phi = 0.988$.

Thermal conductivity of brick at 587°C = 7.81 Btu/h ft² °F/in. The overall coefficient of heat transfer between gas and blast, for the zero order Eigenfunction can now be calculated as

$$U_0 = 0.66 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

Specific heat of checkers at mean brick temperature

$$= 0.231 \text{ Btu/lb } ^\circ\text{F}$$

Density of checkers = 120 lb/ft³. Therefore from equation (16) $\Pi = 6.24$

W_1 = heat capacity of gases at mean gas temperature of 670°C

$$= 2.29 \times 10^4 \text{ Btu/h } ^\circ\text{F}$$

W_2 = heat capacity of blast at mean blast temperature of 505°C

$$= 4.31 \times 10^4 \text{ Btu/h } ^\circ\text{F}$$

A = checker heating surface area

$$= 186810 \text{ ft}^2.$$

The heating surface of the cross flue channels is not included, as it is thought that they will not contribute to the effective heating surface area of the stove since the cross flow between channels, and therefore the heat transfer, will be very small on a relatively newly bricked stove which is free from blocked channels.

TABLE IV Summary of test results

Stove	Checker type	Heating surface area, ft ²	Blast vol., n ft ³ /min	Blast temp., °C	Mean gas inlet temp. to checkers, °C	Mean stack temp., °C	Cycle time, h	Stove performance calculated from theory, (Btu/cycle)	Actual stove performance on test, (Btu/cycle)	Performance, actual expected
A	McKee	186 810	42 500	875	1 190	150	6.88	206 × 10 ⁶	200 × 10 ⁶	0.972
A	Repeat test									
	McKee	186 810	42 500	800	1 220	169	8.97	277 × 10 ⁶	260 × 10 ⁶	0.940
B	Freyne	160 970	41 000	705	1 150	290	5.62	118 × 10 ⁶	113 × 10 ⁶	0.957
C	Stein	115 500	38 600	705	1 190	215	6.49	108 × 10 ⁶	116 × 10 ⁶	1.073
D	Hotspur	134 570	41 000	750	1 200	137	6.41	132 × 10 ⁶	139 × 10 ⁶	1.052
E	Brassert	165 550	23 050	980	1 190	196	3.69	109 × 10 ⁶	69 × 10 ⁶	0.643
F	Hotspur	166 500	31 000	970	1 200	220	2.26	70 × 10 ⁶	75 × 10 ⁶	1.070

Therefore from equation (15)

$$A = 16.3$$

Using these values of Π and A , U/U_0 is read from Fig. 5 as 0.855. Thus the true overall heat transfer coefficient between gas and blast

$$U = 0.564 \text{ Btu/h ft}^2 \text{ } ^\circ\text{F}$$

(ix) *Logarithmic mean temperature difference between gas and blast* From Fig. 8 the LMTD is calculated as

$$\Delta t_m = 284^\circ\text{F}$$

(x) *Stove performance calculated from regenerator theory* The heat transferred/cycle is calculated from equation (19). Therefore

$$Q = 6.880 \times 0.564 \times 186\,810 \times 284 = 206 \times 10^6 \text{ Btu/cycle}$$

(xi) *Actual stove performance* The actual stove performance is calculated from the blast volume and temperature.

$$\text{Blast volume} = 42\,500 \text{ n ft}^3/\text{min}$$

$$\text{Blast temperature} = 875^\circ\text{C}$$

$$\text{Blast period} = 2.53 \text{ h}$$

$$\text{Heat in steam addition to blast} = 0.47 \times 10^6 \text{ Btu/h}$$

$$\text{Increase in sensible heat of blast in stove} = 32.6 \text{ Btu/standard ft}^3$$

$$\begin{aligned} \text{Therefore stove performance} &= 42\,500 \times 60 \times \frac{492}{520} \times 32.6 \times \\ &25.3 + 0.47 \times 10^6 \times 2.53 \\ &= 200 \times 10^6 \text{ Btu/cycle} \end{aligned}$$

This value compares well with the stove performance calculated using the regenerator theory.

Summary of test results

The results of seven hot blast stove tests conducted at various works are given in Table IV, where a comparison is shown of the actual stove performance and the performance calculated from Hausen's regenerator theory.

It will be seen from Table IV that the calculated performance agrees surprisingly well with the actual performance in all cases, except for test E, where the calculated duty is well above the duty actually obtained during test. It was known, however, that this

stove (an old one) offered a high resistance to gas flow, indicating that there was blockage in the checkers. If the gas is channelling through the stove checkers then a certain amount of heat transfer area is rendered inoperative with the result that a calculated heat transfer using the total heating surface area gives an overestimate of stove performance.

The greatest source of error in the calculations was undoubtedly in the evaluation of the gas temperature entering the checkers. A 'dome temperature' record will not necessarily read the true gas temperature (or, for that matter, the true dome temperature). The calculation of the gas temperature entering the checkers from consideration of heat transfer to the combustion chamber is possibly a little better, but the use of a suction pyrometer in the stove dome is the only satisfactory method of obtaining the true gas temperature (and one would like to think that this may become a standard installation).

It is not suggested that the whole problem of stove design is once and for all settled by the application of the Hausen theory. However, it is clear that progress can be made by using this method, in a way just not conceivable with the rule-of-thumb design systems now in common use. At the same time it is encouraging to see the number of attacks in progress on the problem from different points of view, both theoretical and experimental, and it cannot be doubted that these will provide an enormous impetus to stove design.

RELATIONSHIP BETWEEN OPERATING VARIABLES FOR THREE- AND FOUR-STOVE SYSTEMS FOR A GIVEN STOVE DUTY

The regenerator theory, previously described, and verified over the normal operating range of the stoves tested, has been adapted to a computer program and the effect of a number of variables on the heating surface requirements of three- and four-stove systems has been studied assuming the theory to hold over more extreme conditions. The variables studied are given in Table V. The stove duty of all the systems examined has been taken as 100 000 n ft³/min at 1000°C and 30 lb/in² gauge, this being considered a realistic immediate future blast-furnace requirement for new installations. The inlet cold blast temperature has been taken as 95°C.

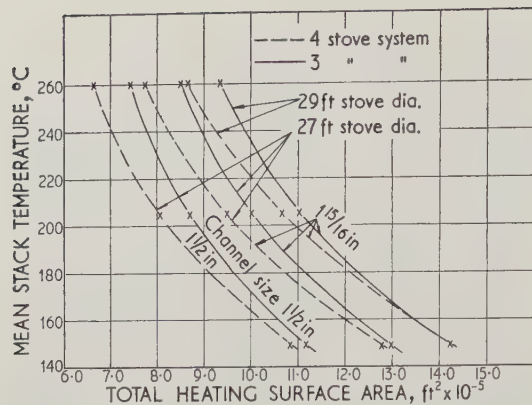
Figure 10 shows the influence of stack temperature, for a given dome temperature, on the total heating surface area of three- and four-stove systems. For a given checker size, stove dia., and dome temperature, the total heating surface area of the four-stove system is slightly less than that of the three-stove system at any particular stack temperature. This reduction in

TABLE V Operating variables used in the study

Time-mean gas temperature at top of checkers, °C	1 150	1 200	1 260
Time-mean stack temp., °C	150	200	260
Total checker free flow area, ft ²	100	125	150
Checker hole size, in	1½	1⅝	
Checker wall thickness, in	1.25		
Cycle time, h	1	2	4

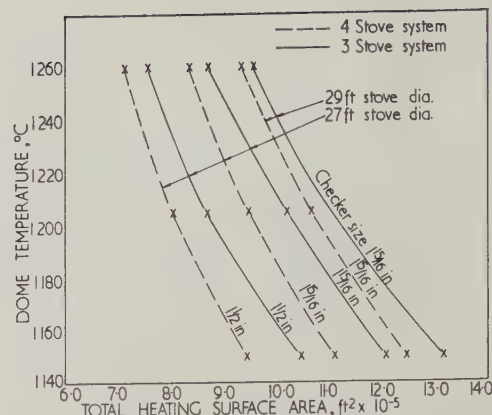
3-stove system : 1 on blast, 2 on gas

4-stove system : 2 on blast (staggered parallel), 2 on gas.



Stove duty: 100 000 n ft³/min, 1000°C, 30 lb/in² gauge
 Constant dome temp.: 1200°C
 3-stove: 1 h blast period, 2 h gas period
 4-stove: staggered parallel operation 2 h blast period, 2 h gas period
 Cold blast temp.: 95°C

10 Relationship between mean stack temperature and total heating surface area for three- and four-stove systems



Stove duty: 100 000 n ft³/min, 1000°C, 30 lb/in² gauge
 Mean stack temperature: 200°C
 3-stove: 1 h blast period, 2 h gas period
 4-stove: staggered parallel operation 2 h blast period, 2 h gas period
 Cold blast temp.: 95°C

11 Relationship between dome temperature and total heating surface area for three- and four-stove systems

total heating surface area becomes more pronounced at higher stack temperatures. The effect of reducing the checker size is clearly shown; the reduction in heating surface area is accounted for by the increase in the convective heat transfer coefficients (although at the expense of increased pressure drop).

Increasing the stove diameter for the same checker size increases the heating surface area because the increase in free checker area, causing a reduction in the fluid velocities, results in lower convective heat transfer coefficients.

The influence of dome temperature for a constant stack temperature on heating surface area is shown in Fig. 11. A reduction of 23% in heating surface area is effected by increasing the dome temperature 100°C for the four-stove systems, while the corresponding reduction of heating surface area for the three-stove systems is 26%.

Cycle time is plotted against heating surface area for a given dome and stack temperature in Fig. 12. It is seen that there is an optimum cycle time which gives a minimum heating surface area. For the conditions considered this optimum is between 45 and 60 min for the three-stove system and between 120 and 210 min for the four-stove system. If shorter periods than these are used the heating surface area increases rapidly because the changeover time, assumed to be 10 min/cycle, becomes an important proportion of the cycle time. The optimum cycle time is slightly different for the various conditions assumed. Increasing the cycle time beyond the optimum value has a much smaller influence on four-stove heating surface area than for a three-stove system. The difference in shape of curve between three- and four-stove systems arises as follows. In the four-stove system the increase in surface area with increase in cycle time beyond the optimum is a result solely of the Hausen *A* and *II* end corrections. In the three-stove system there is also the effect of by-pass air, which increasingly reduces the effective LMTD as cycle time increases.

The practical significance of Figs. 10–12 is complex, and a full discussion is reserved for a later paper. The possibility of reducing checker size is limited, perhaps, by the danger of blockage, and also by the increased

pressure drop necessitating boosting gas pressures at the burner. On the other hand the redesign of gas burners is long overdue, and many installations are already limited by both burner and combustion chamber design.

Height/diameter ratios are again limited by such practical considerations as the danger of refractory failure (by thermal stress) if a certain critical value is exceeded; here the whole mechanical problem of stove refractory design needs re-examination.

The influence of dome temperature is important, and the introduction of improved refractories is strongly urged. On the other hand, with the increasingly lower CV blast-furnace gases now available, adiabatic flame temperatures are falling, and higher dome temperatures may necessitate upgrading with coke-oven gas.

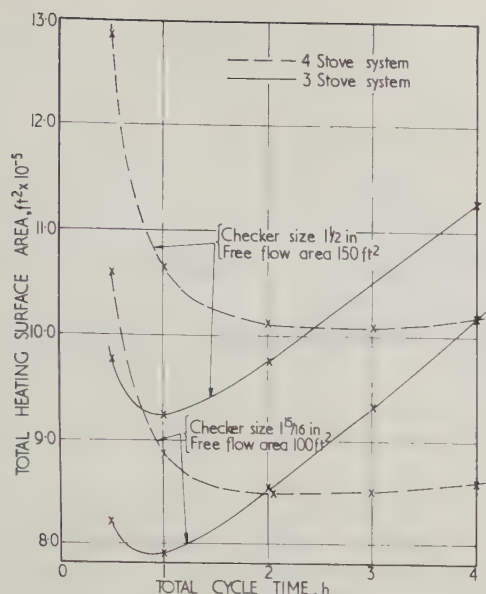
The need to work at shorter cycle times clearly involves good automatic changeover equipment. A new stove operating at very short cycle times could well differ considerably from existing stoves, particularly from the point of view of brick thickness. Problems of the effect of thermal cycling, and of the time to flush out before changing over, would need examination.

A reduction of changeover time is clearly advantageous, and the problem is different in three- and four-stove systems, since, in the former, changeover time comes out of the gas period, and any reduction in time would necessitate increasing the gas combustion rate within a given combustion chamber.

Finally, the whole problem of burner and combustion chamber design has, in this paper, been ignored although it is possible to envisage radically new designs which will have a marked impact upon stove performance.

COST OPTIMIZATION OF THREE- AND FOUR-STOVE SYSTEMS

The stove designer has a certain latitude in his choice of operating conditions when considering a stove system to meet a certain duty, but he will be attempting to produce a design which has a minimum capital and operating cost coupled with sound engineering.



Stove duty: 100 000 n ft³/min, 1000°C, 30 lb/in² gauge
Dome temperature: 1200°C
Mean stack temperature: 200°C

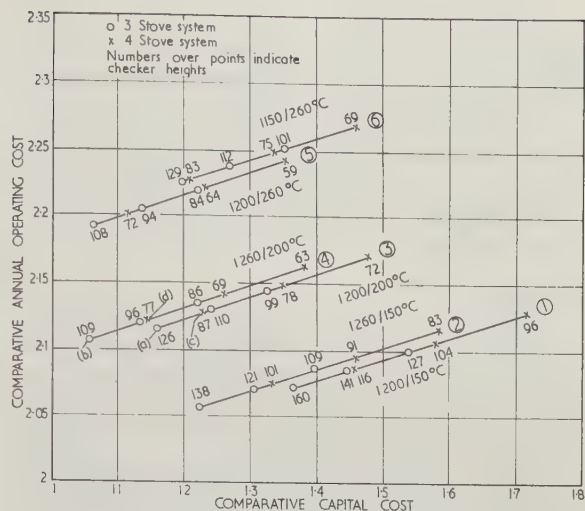
12 Total heating surface area against total cycle time

For the purpose of making a comparison of three- and four-stove systems on a cost basis, using a range of operating conditions, a stove duty of 100 000 n ft³/min at 1000°C and 30 lb/in² gauge has again been chosen. The stoves previously calculated, using the operating conditions given in Table V, have been evaluated in terms of capital and operating costs.

The three-stove system has been assumed to work with a 3-h cycle, and the four-stove system in staggered parallel on a 4-h cycle.

The heating surface area, checker height, and stove dia. have been calculated and the capital cost of each system obtained. The annual operating cost can be calculated assuming that the capital and debit interest is repaid over a 15-year period, and blast-furnace gas is taken as 5d/1000 ft³ for a 92 Btu/ft³ gas, which, so far as the authors can ascertain, is a reasonable average for the UK. The cost of gas is of major importance in the calculations which follow, and it is important that, in any actual case, a true (and not merely an accountant's) figure shall be used. It is also possible that in other countries (e.g. the USA) the value of blast-furnace gas may be considerably modified by the existence of large supplies of cheap natural gas; pumping and fan power costs for combustion air are included in the annual operating cost.

A selection of the results obtained is plotted in Fig. 13 which shows the relationship between capital and annual operating cost for three- and four-stove systems for various combinations of dome and stack temperature. Three points for the three-stove system corresponding to 100, 125, and 150 ft² of free checker area and three points for the four-stove system for the same free flow areas are plotted on each line. These free flow areas correspond to stove diameters of 25.5, 27.5, and 29.0 ft respectively. The least free checker area and smallest stove diameter occurs at the bottom left-hand of each line. The number marked above each point indicates the checker height of the particular stove. The temperatures in the figure correspond to inlet and stack gases.



Stove duty: 100 000 n ft³/min, 1000°C, 30 lb/in² gauge
Checker: McKee (1 1/8 in square holes, 1 1/2 in wall thickness)
Cold blast temperature: 95°C
3-stove: 1 h blast period, 2 h gas period
4-stove: staggered parallel operation, 2 h blast period, 2 h gas period

13 Relationship between capital cost and annual operating cost for three- and four-stove systems

The curves show the marked influence of stove thermal efficiency. Thus stoves on line 3 have a greater thermal efficiency than stoves on line 5 and the operating costs of the less efficient stoves are correspondingly higher. Still, considering lines 3 and 5, and imposing some arbitrary limitation in checker height (say 110 ft) it will be seen that the minimum capital cost for a three-stove system of lower efficiency (1200/260°C) is 1.06, while a more efficient stove (1200/200°C) of the same checker height could be built for not less than 1.24 capital cost. However, the corresponding annual operating costs (which include a proportion of the capital) would be 2.19 and 2.13 respectively. The choice between these stoves thus becomes a matter for the accountant. Note that the annual blast-furnace gas costs (at 5d/1000 ft³) are more than half the annual operating costs. If the thermal efficiency is increased still further (line 1) then the checker height of the three-stove system becomes too great to be considered for practical reasons, and the four-stove system assumes corresponding importance.

Increasing the dome temperature while maintaining the same stack temperature for a stove of the same diameter (compare points (a) and (b) for three-stove system and points (c) and (d) for four-stove system) produces both a lower capital and operating cost and gives a reduced checker height. This difference in costs becomes more pronounced if a higher stack temperature is selected.

For a given dome temperature, stack temperature and stove diameter, the three-stove system will always give a lower capital and operating cost than the corresponding four-stove system (compare points (b) and (d)) but the checker height of the four-stove system is considerably less than in the case of the three-stove system.

Progressively decreasing the stove diameter (with consequent increase in checker height), for a given dome and stack temperature, always produces a lower capital and operating cost, for either a three- or

four-stove system, but one practical limitation (among others) is imposed owing to the increased pressure drop caused by the reduction in checker free flow area. The curves have therefore been terminated arbitrarily at a free checker area of 100 ft². These remarks lead to considerations of the possibility of providing gas boosters and the use of a pebble packing to replace conventional checkers. The economic considerations involved here are, however, outside our present scope.

Existing stoves

The emphasis in the last section has been on new installations. It seems most unlikely, however, that existing stoves operate nearly at optimum conditions. By means of simple tests of the kind discussed it is possible to evaluate the parameters of an existing installation. Using Hausen's theory it is then possible to compute how the installation should behave under other operating conditions. It seems likely that, with automatic changeover, shorter cycle times, and redesign of burners, perhaps with gas boosting, marked improvements in performance may be obtained. The results of such calculations will form the subject of a later paper.

SUMMARY AND CONCLUSIONS

1. The practical tests have demonstrated that the use of Hausen's regenerator theory and Bohm's equation for heat transfer coefficients provides a reliable method for the thermal design of hot blast stoves. The influence of operating conditions on the stove design can be assessed by adapting the theory to a computer program.

2. Cycle times can be optimized, in theory, for both three- and four-stove systems, to give a minimum heating surface area requirement.

3. The cost of blast-furnace gas (at average UK values) accounts for more than half the annual operating cost including depreciation and debit interest so that stove thermal efficiency has a marked effect on operating costs.

4. For a given dome temperature, stack temperature, and stove diameter, a three-stove system gives a lower combined capital and operating cost than a four-stove system. The stove height in the four-stove sys-

tem will be considerably less than the stove height in the three-stove system. On the other hand a much more complex system of mains, valves, and controls is required.

5. For given dome and stack temperatures, a progressive decrease of stove diameter, with consequent increase in checker height, always produces lower combined capital and operating costs for either three- or four-stove systems. Practical limitations, such as pressure drop (on the gas side) and refractory strength, must then be considered.

6. Blast-furnace gas pressure is a bottleneck preventing the introduction of new stove designs which would have much lower capital costs than present design. The boosting of gas pressures, and the radical redesign of burners and combustion chambers must now be undertaken.

7. The application of the Hausen regenerator theory is only one aspect of a great deal of work, theoretical and experimental, now in process throughout the world, and this is bound to lead to radical changes in stove design, to meet rapidly changing blast-furnace requirements, within the next few years.

ACKNOWLEDGMENTS

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Blast-furnace refractories

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INTRODUCTION

THE EVOLUTION of the blast-furnace to its present state of efficiency has extended over many years, and there is no evidence that the peak of efficiency has yet been reached.

Perhaps the most obvious development has been the trend to larger furnaces, illustrated by the fact that in 1933 there were 332 blast-furnaces installed in this country producing on average 1110 tons of iron per furnace per week while in 1942 the number of blast-furnaces in blast had been reduced to 157 but weekly output had been raised to over 1500 tons.¹ Even these figures seem small compared with present-day outputs of 8000–10000 tons/wk from several furnaces. Blast volumes and temperatures have been raised and the increasing use of sinter or prepared burdens has also played its part in increasing the rate of production of iron for a given size of furnace.

Needless to say these advances have thrown increasing strain on the materials of construction of the furnace, including the refractories with which it is lined. During the last 30 years or so there has been close co-operation between ironmakers and the refractories industry aimed to provide refractories to meet the changing conditions introduced by new iron-making techniques. This co-operation is exemplified by what is now known as the Blast-Furnace Refractories Joint Committee of the British Iron and Steel Research Association and the British Ceramic Research Association. This Committee can trace its lineage back at least to 1930.

The joint efforts of ironmakers and brickmakers to improve the life of the blast-furnace lining have resulted in improvements in refractories and parallel improvements in furnace design, such as the more extensive use of cooling. It is the purpose of the present paper to review recent developments in refractories for the blast-furnace proper and these will be considered separately in relation to the different parts of the furnace for which they have been specially introduced. An attempt will also be made to identify those problems which require further attention before maximum economic advantage can be obtained from improved practice and blast-furnaces can consistently give high outputs at high rates of production using increasingly inferior ores.

SYNOPSIS

The paper outlines the progress made in the selective application of refractories for lining various parts of the blast-furnace to meet the more severe conditions developing with faster furnace operation and the increasing use of sinter.

The development of improved grade stack refractories to meet a 'manufacturers' aim' evolved by the BISRA/BCRA Blast-Furnace Refractories Committee is outlined and the results so far obtained in service are discussed.

A description of the spiral bricksetting of stack refractories to give faster relines and eliminate cutting of the very hard improved grade stack refractories is included together with some thoughts on future trends in blast-furnace linings.

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HEARTH AND BOSH WALLS

Before the second world war, the majority of furnaces had fireclay linings throughout, and in general, the limiting factor in the life of the lining was considered to be the hearth and bosh walls. Breakouts were experienced which frequently resulted in furnaces having to be taken out of service while the remainder of the refractories were still in good condition. It was natural therefore that much development effort was concentrated on the provision of improved refractories for these parts of the furnace.

The steps which led to the introduction of carbon refractories and their success in the hearth and bosh walls are now well-known.² Plants which had had bad breakout records were freed from these troubles and the examination of linings after service showed the carbon refractories to be still in reasonable condition. Much of the success of carbon must be attributed to its high thermal conductivity, permitting more effective cooling and lower surface temperatures on the refractories, but it also shows much greater volume stability at high temperatures than many firebricks and is relatively non-wetted by iron and slag. Typical properties are shown in Table I. In particular it will be noted that the thermal conductivity is almost three times that of firebrick.

TAPHOLE REFRACTORIES

Although carbon has proved generally successful in the hearth walls, and is almost universally used, opinions differ on its use in the immediate vicinity of the taphole. When carbon is chosen for the refractory in this

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TABLE I Typical properties of carbon blast-furnace refractory

	Carbon	35%Al ₂ O ₃ Firebrick
Reheat shrinkage (2 h at 1500°C), %	0.42	2.4
Thermal conductivity at 1000°C, Btu/h ft ² in °F	27.5	9
Porosity, %	18	21
Bulk density, lb/ft ³	95	126
Abradability index (Morgan- Marshall test)	180	270

position there is a severe risk of oxidation, either due to ingress of air or more possibly as a result of the oxidizing action of the moisture in conventional taphole clays.

There are two possible answers to this problem: firstly, to retain the carbon around the taphole and to use a non-aqueous taphole filler, or secondly, to use a taphole surround in a refractory which is resistant not only to iron and slag but also to oxidation. Both these methods have been tried with some measure of success although there is as yet little sign of widespread adoption of any particular procedure.

Many experiments have been carried out on the use of tar-bonded taphole fillings, and although there have been claims of success, other operators have frequently been unable to reproduce the results. There is undoubtedly some resistance to the use of these materials, probably associated with the fumes which can be created in certain circumstances, but it also appears that more powerful guns and drills than are commonly available are required to handle this type of material satisfactorily; so that it would be wise to await further developments before passing judgment.

The second method has been tried with some degree of success using high alumina bricks. However, the conventional refractory bricks usually erode to a considerable degree during a campaign, so that with potentially higher furnace output a better material is required and it may be that a fusion cast refractory of extremely low permeability and good resistance to attack by iron and slags will provide a solution.

FURNACE BOTTOMS

It was natural that when carbon was introduced into the hearth walls, it should also be tried in the bottom. The results here were much less definite.

Examination of blown-out furnaces invariably showed an almost complete disappearance of the carbon bottom and a substantial bear reaching well down into the firebrick sub-hearth. Undoubtedly the use of carbon against the shell in the furnace bottom has prevented breakouts but any other advantage of a carbon bottom compared with firebrick is less positively defined.

Where carbon bottoms are used there are still divided opinions as to the advantages of large blocks compared with smaller, interlocking, pieces. The British Iron and Steel Research Association organized a conference on carbon hearths in 1946³ at which the relative merits of the two constructions were discussed inconclusively. The position is still exactly the same some 15 years later.

The major difference between the use of carbon in the bosh and hearth walls and in the bottom appears to lie in the effect of cooling and in the temperature

gradients involved. In the walls the high thermal conductivity of carbon permits effective cooling and the carbon surface temperature is such that a thin layer of slag and iron is retained on the surface protecting it from further attack and erosion. The surface temperature in a normal carbon bottom is much higher owing to the absence of cooling, and in this case the high thermal conductivity is a disadvantage, leading to a relatively shallow temperature gradient which permits deep penetration and solution by molten iron.

Theoretical consideration was given to this problem by Voice in 1952.⁴ He proposed that for an 18-ft dia. hearth furnace a carbon bottom of about 6 ft thickness with air cooling immediately below should be employed. Similar ideas were being taken up in Austria, Sweden, and the USSR, where under-hearth cooling was being tried with hearths constructed of a carbon pad laid on firebrick.

Voice's ideas were incorporated in one furnace in 1957.⁵ This furnace was blown in during 1958 and after a few months operation the same ironworks was sufficiently encouraged to modify another furnace using an improved air cooling system. Examination of these hearths when the furnaces are blown out should provide valuable data for future designs of furnace bottoms. In the meantime, many types of bottom, both carbon and firebrick, are in use.

One of the problems associated with carbon refractories is that of oxidation during blowing in. The usual practice of protecting the carbon with a 4½ in or 9 in layer of low-duty firebrick has generally been effective but troubles have arisen owing to the lining bricks breaking away and blocking slag and iron notches. Recent experiments using a thin layer of a refractory castable, gunned over the carbon, have proved successful in two furnaces which have been taken into service using this practice. In one case a layer of 1–1½ in of refractory gunning material was applied to a new carbon construction and in the second case a similar layer was applied to carbon being used for a second campaign. The advantage of this technique for protecting an uneven surface was very apparent in the latter case. Both furnaces were blown in without difficulties and slagging and tapping operations proceeded smoothly.

STACK REFRACTORIES

The factors affecting refractory performance in the stack of the blast-furnace have been the subject of extensive investigation and conjecture for a good many years. Both mechanical and chemical attack occur and as the latter usually involves at least one reactant in vapour form, investigation of the problem is very difficult.

Stack refractories have gradually developed from large blocks of 30–35%Al₂O₃ materials to the present when the majority of furnaces employ 9 in and 13½ in brick sizes in 42–44%Al₂O₃ grades based on Scottish fireclays and having properties approximating to those shown in Table II. The reduction in size has permitted the refractories to be fired more satisfactorily and manufactured to better dimensional standards.

Stacks lined with this type of refractory give good service in many cases, producing generally around 1 million tons of iron between relines. The wear on the stack refractories during a campaign usually follows a set pattern, showing heavy wear in the top third, less

TABLE II Properties of 42%Al₂O₃ stack refractory

Al ₂ O ₃ , %	43
SiO ₂ , %	51
Fe ₂ O ₃ , %	2.6
TiO ₂ , %	1.3
Bulk density, g/c ³	2.10
Apparent porosity, %	19.5
Reheat shrinkage, 2 h, 1410°C	Less than 0.5%
Abradability index (Morgan-Marshall apparatus)	Outside of brick 130 Inside of brick 200

wear in the middle section and severe erosion in the lower third. The blown-out lines of a typical furnace are shown in Fig.1. Scaffolds, the formation of which was carefully investigated by Rigby,⁶ often affect the furnace lines but their main effect appears to be on furnace blowing and output rather than on breaking up the refractories. Blown-out furnaces usually show the refractories to have been attacked by carbon monoxide, alkalis, and mechanical abrasion. Frequently substantial quantities of zinc compounds are present but there is doubt about the effect of these on the refractories.

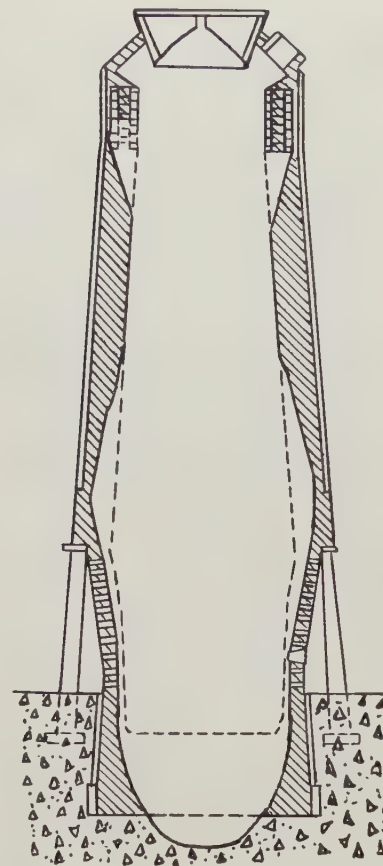
In recent years it has, however, become apparent that this type of stack lining is not adequate for satisfactory operation of large furnaces, driven hard, on low-grade ores or sinter burdens. In these cases the introduction of carbon walls for the lower parts of the furnace has left the stack as the limiting factor in the length of campaign.

To meet this situation, and following observations of blown-out furnaces over many years, the Blast-Furnace Refractories Joint Committee introduced a 'manufacturers' aim' which set out the principal properties considered necessary for an improved blast-furnace stack refractory. These aims were circulated to brickmakers and were described by H. M. Richardson to the Blast-Furnace Conference in 1957. The first lining of this type was installed in the same year. Four properties were considered to overshadow all others:

- (i) true porosity less than 15%
- (ii) resistance to carbon monoxide attack to be complete on a 200 h test*
- (iii) reheat shrinkage held for 2 h at 1410°C to be nil
- (iv) abrasability index less than 100 on the Morgan-Marshall apparatus†

These aims represent a very considerable advance, and by using such refractories the ironmakers hoped to be able greatly to improve stack life even under the most arduous operating conditions.

The manufacturers' aim gave no indication of the chemical requirements, these being considered to be of lesser importance if the other properties were achieved. One chemical requirement is, however, implied by the specification of resistance to carbon monoxide disintegration since Hugill *et al.*⁷ established that this effect is catalysed by iron spots in the brick. While several authorities claim that high temperature kilning renders the iron inert to the effects of carbon monoxide, reports have been made of carbon monoxide attack on stacks lined with bricks which have passed the recognized 200 h laboratory test. Very low iron content in the refractory is obviously desirable even if



1 Used furnace lines

high kilning temperatures are employed during manufacture.

Much work has been carried out to devise a laboratory test which will remove some of the anomalies found in the present test for carbon monoxide disintegration, and which will enable an assessment to be made of the effects of zinc and alkalis. So far the only reliable test known is in the blast-furnace itself.

The manufacture of a brick to a true porosity less than 15%, equivalent in most cases to an apparent porosity of 6-7%, while maintaining close dimensional tolerances, demands very close control of the manufacturing process. It is possible to achieve this, and lower porosities, by hard firing of certain clays, but very high firing shrinkages occur, leading to distortion and erratic dimensions. To produce a brick of the quality desired for the most advanced stack refractories, low-porosity, hard fired clay briquettes, or alternatively naturally occurring high-temperature stable minerals of low porosity, are taken, crushed, graded, and rebonded. In this way a minimum of shrinkage occurs on firing and dimensional accuracy is maintained. It will readily be appreciated that this process is much more expensive than the normal process for manufacture of fireclay refractories. The approximate relative costs of linings for a typical furnace are as follows:

'Conventional firebrick'	£12500
Special dense stack refractory	£50000

Since the actual cost of relining such a furnace is in the region of £140000 the extra brick cost is quickly justified by greater iron production per lining, quite

* BS.1902, 1952.

† *Trans. Brit. Ceram. Soc.*, **54**, no.4, 1955.

apart from the advantages to be gained by greater furnace availability. In the case of a really large furnace the increase in total cost may only be 20%.

During the development of these improved stack refractories many slag tests were carried out on a wide variety of samples and several of these are shown in Fig. 2.

Each of these samples was heated to 1300°C in a gas-fired furnace containing graphite to produce a carbonaceous atmosphere.

Samples A, B, C, D, E, and K were heated for 6 h and contained 60 g of slag which consisted of a mixture of 98% home ore sinter + 2% K_2CO_3 .

Samples F, G, H, and I were tested using a charge of 5 g fusion mixture (60% K_2CO_3 40% Na_2CO_3), 0.25 g ZnO_2 and 0.25 g $FeCl_2$.

It is interesting to note in the sinter test that the china clay refractories show a slight erosion and penetration down the large pore cavities while the higher alumina samples, although showing extensive penetration, show a rather smaller amount of erosion. The fusion mixture caused most of the high alumina samples to split while the china clay sample was unaffected. These tests are obviously very remote from service conditions in a stack but they have been reproduced in mobile slag tests.

Abradability indices of less than 60 have been obtained with super-duty blast-furnace refractories.

Published properties of improved refractories which are now in service in stack linings are shown in Table III. It will be seen that the first two meet the manufacturers' aim while the third is near to it. Grade I is an all china clay refractory and grade III is an all sillimanite refractory.

In order to obtain the optimum service from these super-duty low-porosity refractories it is essential that the lining is bricked as tightly as possible with the thinnest possible joints. The mortar used should produce a hard joint which is not affected by the operating conditions in the stack. Some difficulty has been experienced in cutting these abrasion-resistant

TABLE III Properties of improved stack linings

	Manufacturers' aim	Grade I	Grade II	Grade III
True porosity, %	15	11	10-12.5	15.5-16.5
Reheat shrinkage (2 h, 1410°C)	Nil	Nil	Nil	Nil
Resistance to CO	Complete	Complete	Complete	Complete
Abradability index	Less than 100	45	40-57	40-70
Al_2O_3 , %	...	43.1	39.5-40.5	60-61
SiO_2 , %	...	53.8	55	Balance
Fe_2O_3 , %	...	0.7	1.8	0.3-0.6
TiO_2 , %	...	0.1	0.8	1.0-1.8

Note: All data taken from manufacturers' catalogues

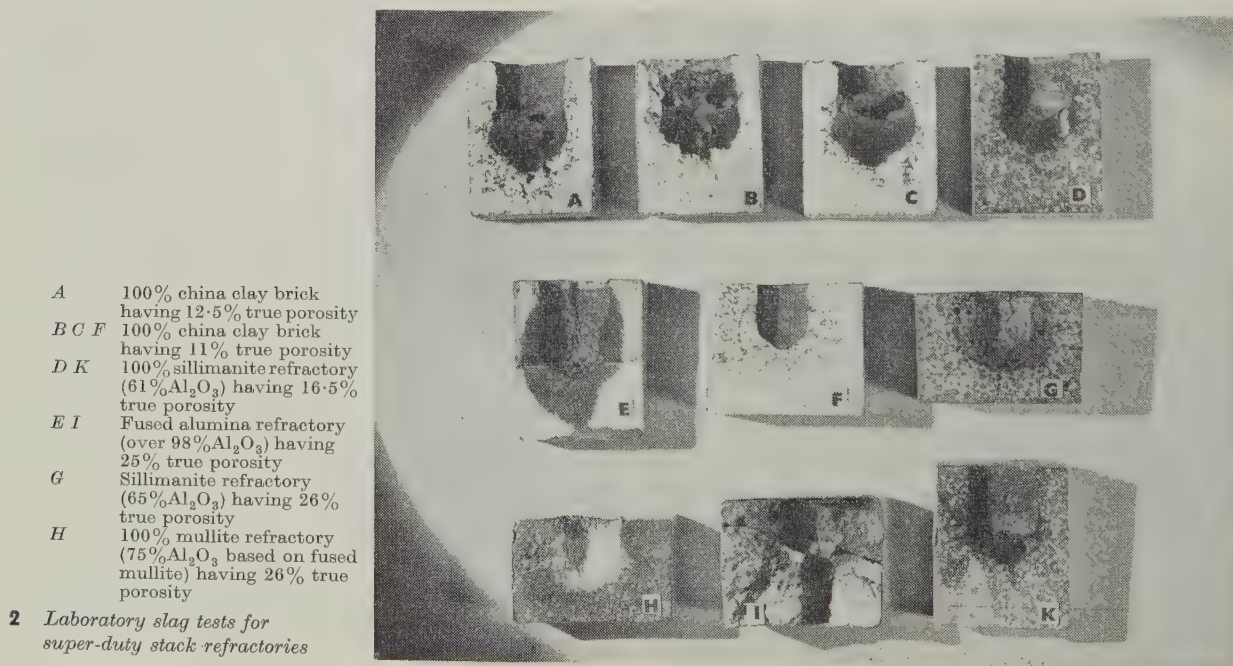
bricks, and to avoid this a series of closure bricks has been introduced for completing each ring.

An alternative system of bricking using a spiral pattern which eliminates closures is illustrated in Fig. 3. In this instance a two-start spiral was started in the carbon and continued up to the throat armouring. The stack lining was 22½ in thick, consisting of one ring of 9 in bricks and one ring of 13½ in bricks. Four bricklayers worked together bricking continuously, and changeover from ring to ring caused no difficulty. The coolers were set in a refractory concrete, bricking as close to the cooler as possible, then filling the space with the concrete.

The throat armouring in this furnace was also held in place by the same refractory concrete.

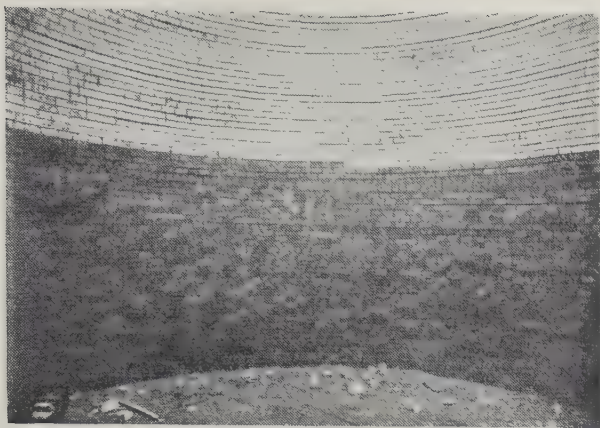
Obviously where space is available a spiral with a greater number of starts or a deeper ramp can be used permitting more bricklayers to work together. A modification of this technique where the start of the spiral is incorporated in the dense brick itself is shown in Fig. 4. Since the brick is more difficult to cut than the carbon the spiral should be started in the latter if possible.

As far as is known to the authors ten furnaces incorporating one or other of the stack refractories listed in Table III are in operation, two have been blown out (not because of failure of the dense brick), and a number of others are under construction. The



- A 100% china clay brick having 12.5% true porosity
 B C F 100% china clay brick having 11% true porosity
 D K 100% sillimanite refractory (61% Al_2O_3) having 16.5% true porosity
 E I Fused alumina refractory (over 98% Al_2O_3) having 25% true porosity
 G Sillimanite refractory (65% Al_2O_3) having 26% true porosity
 H 100% mullite refractory (75% Al_2O_3 based on fused mullite) having 26% true porosity

2 Laboratory slag tests for super-duty stack refractories



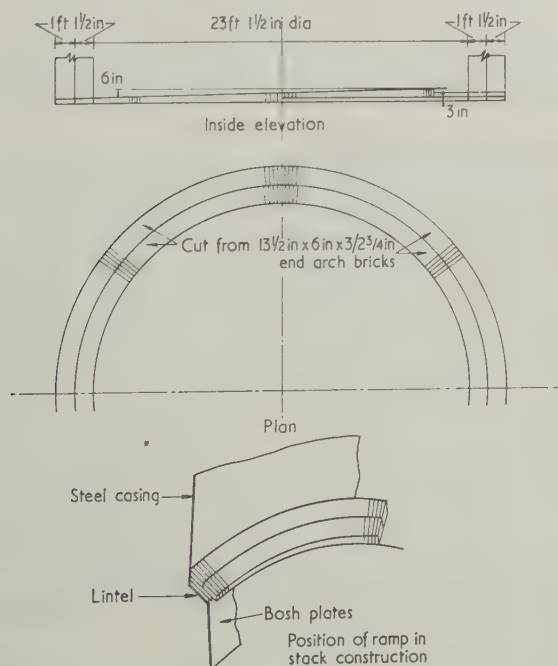
3 Spiral brick setting showing the start of the spiral in the carbon refractories

two stacks which have been examined to date incorporate grade I in Table III, the china clay brick, and in both cases the results are impressive.

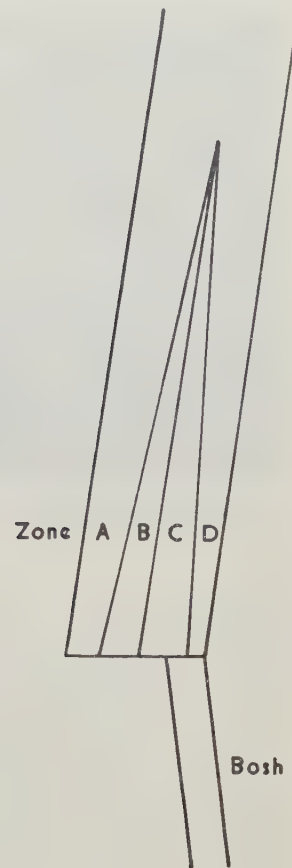
In the first case the furnace had made over 920 000 tons of iron from a fully sintered home-ore charge containing about 36% iron before being taken off because of failure of ancillary equipment. This output was some 50% greater than had been achieved with a conventional 42% Al_2O_3 stack refractory which had in the past been the limiting factor in the length of a campaign.

In this particular case an unusual opportunity occurred to inspect the lining when the furnace was shut down because of a recession in trade after making 270 000 tons of iron in about one year. The lining was cut back to some extent above the bosh tuyeres, but above this level and between the tuyeres was perfect.

When finally blown out the upper two-thirds of the stack were almost as new showing no signs of abrasion



4 Construction of 6in ramp for spiral bricking of blast-furnace stack



5 Diagram of flaked zones in blast-furnace stack refractories

or carbon monoxide attack. The bottom third showed flaking of the refractory midway through its thickness with sound brickwork in front and behind.

A second furnace operating under similar conditions and lined in a similar manner has produced over $1\frac{1}{2}$ m. tons of iron and the lining appears to be still in very good condition.

The flaking observed in the blown-out furnace was most unusual and had not previously been recorded. The region involved is indicated in Fig. 5 and it is immediately apparent that it may be associated with the isothermal surfaces in the lining. The actual form of flaking is indicated in Table IV at a point 8–10 ft above the lintel.

The flakes themselves were still very strong and the almost complete absence of carbon deposition indicated that failure was not due to carbon monoxide disintegration.

X-ray examination of the flaked zone showed the

TABLE IV Diagrammatic section through a super-duty stack lining 8–10 in above lintel, after service

Shell	A About 9in	B About 4in	C About 12in	D About 3in	Hot face
Region A consisted of solid brick mainly white in colour					
Region B consisted of flakes up to $\frac{1}{4}$ in thick, with fractures parallel to the hot face. Most of these were coated with grey and green deposits. Some flakes were also impregnated with green material. The matrix generally was black in colour.					
Region C consisted of large flakes 1–4 in thick, stained black					
Region D consisted of solid brick, and shows a white grog in a dark-coloured matrix.					



6 Part of an upper stack lined with a china clay refractory after making 600 000 tons of iron

presence of considerable proportions of zincite ZnO , sphalerite ZnS , and anglesite PbSO_4 , but no potassium alumina silicates, such as kalsilite, kaliophyllite, and leucite were detected. It must be presumed that the 4% K_2O present was in the glass matrix of the refractory. The distribution is shown in Table V from which it will be seen that the concentration of potash decreases from the working face outwards, while the zinc is largely concentrated in one region, being mainly present in some of the cracks between the flakes. Some of the cracks were, however, completely clean and free from deposition of any kind. After careful consideration it was concluded that the flaking was not due to deposition of, or attack by, any of the 'foreign' elements present.

By fortunate coincidence a second example of this flaking was reported recently in a furnace lined with a firebrick of the type shown in Table II. The distribution of the flakes was similar to that in the case noted above but all the cracks were quite clean and were not visible until the bricks were removed from the furnace, when they fell apart. In this furnace no zinc deposits were found in the brickwork.

As a hypothesis which appears to fit the presently known facts it is suggested that this flaking is due to thermal stress on blowing out the furnace, the cracks in which zinc compounds were deposited having been formed on the intermediate shut-down of this furnace. It is postulated that this effect has not previously been seen because the brickwork in the area concerned is usually badly disintegrated or even completely lost.

The second furnace examined operated on imported ores and some 60% of the iron bearing burden was sinter. The furnace stack was bricked with a 42% alumina refractory of the type shown in Table II in the lower two-thirds and the super-duty china clay brick (grade I Table III) in the remainder.

After making some 600 000 tons of iron the furnace was taken out of service for repair. The opportunity was taken to examine the stack refractories and it was found that the china clay brick was virtually unmarked and standing well proud of the normal grade brick (Fig. 6). Furthermore, the latter brick was friable and severely laminated while the china clay brick was extremely strong. Laboratory examination showed

TABLE V Analysis on samples of used dense stack refractory

Sample	Loss on ignition, %	Na_2O , %	K_2O , %	Fe^{++} as FeO	Fe^{+++} as Fe_2O_3	Zn, %	Pb, %
A	0.035	<0.1	1.7	0.13	1.0	Nil	...
B	0.35	<0.1	1.5	0.18	0.65	11.3	0.1
C	0.22	<0.1	2.6	0.55	0.1	0.22	0.83
D	0.12	<0.1	3.7	0.35	0.4	0.07	...
New brick	0.05	<0.1	1.5	0.06	0.9	...	...

the presence of kalsilite in both bricks and some signs of the effects of carbon monoxide in the 42% Al_2O_3 grade, although this was not considered to be the cause of lamination. In its previous campaign before installing the super-duty brick, after making about the same tonnage of iron the top of the stack was severely cut back.

Other furnaces using super-duty stack refractories are in service and as far as can be ascertained while the units are in operation the linings are showing very low rates of wear.

MONOLITHIC MATERIALS

Recently there have been reports of repairs to blast-furnace linings using refractory monoliths applied by cement gun. Some work of this nature has been carried out in this country with a considerable amount of success.

In 1956 some 30–40 tons of a refractory guncrete were applied in one furnace in the zone just below the throat armouring and over a wide area just above the lintel. This furnace continued in service for some 18 months producing about 500 000 tons more iron. Another furnace had extensive repairs to the throat area carried out at the end of 1959 with satisfactory results.

Several furnaces have been repaired along similar lines with some degree of success. There will almost certainly be developments in the use of monolithic materials for repairing damaged brickwork but it is unlikely that a monolithic refractory can be produced that will have the same economic potential as the improved grades of stack brick.

FUTURE DEVELOPMENTS

It is unlikely that the blast-furnace will be superseded as the predominant means of ironmaking at least as long as the present rate of improvement in efficiency of operation is maintained. The blast-furnace operator will therefore continually be looking at the weakest link in his equipment in order to increase furnace output between major shut-downs. From the results obtained to date with the improved stack refractories it would appear that this particular section will no longer be the limiting factor in the length of a campaign. Hearth walls, nowadays, so rarely give trouble that the ultimate life of the refractories in this zone is not normally achieved and there is still scope for longer campaigns with the existing refractories. Furnace bottoms are not normally a problem although undoubtedly improved refractories or a widespread adoption of under-hearth cooling should ensure adequate service for many years to come.

Refractory materials in the bosh would appear to be potentially the weakest link in the furnace lining but on campaigns where high slag volumes are being

handled with liberal and efficient water cooling, carbon seems to operate perfectly satisfactorily. Some troubles are being experienced in furnaces operating with rich ore burdens but it is too early to decide whether this is a result of inadequate cooling or insufficient fluid slag to freeze on the surface of the carbon. High alumina refractories having low porosities may be the answer in rich ore practices but the majority of operators still consider carbon to be the most suitable refractory. Some further thought should be given to the means of cooling the bosh refractories and, in fact, to the whole bosh construction. The normal thermal expansion of the refractory will tend to take the bosh brickwork away from the metal casing leaving an air gap between the carbon and the casing, thus reducing the effectiveness of external cooling. Pressure grouting of a carbon- or even metal-containing monolith between the shell and the lining at periods during the campaign is one possible means for ensuring good refractory cooling.

It seems probable therefore that the trend in blast-furnace refractories for the immediate future will be towards an extension of the use of the more progressive techniques discussed. As economic pressures and changes in raw materials lead to further demands on the blast-furnace the use of specialized refractories designed to meet the conditions in specific parts of the furnace will almost certainly increase. It is possible that the more advanced furnaces will have different materials in the bottom, hearth walls, bosh walls, and the bottom, middle, and top of the stack, with the addition of further grades at the taphole and other

highly specialized positions in the furnace. Once the ironmaker has accepted that it is worth while to pay a high price for refractories if they enable him to obtain high outputs and rates of production from his furnaces, and so long as there is a continuation of the co-operation which has existed between ironmaker and brickmaker for the last few decades, there should be no danger of refractories falling seriously short of the demands upon them.

ACKNOWLEDGMENTS

The authors wish to acknowledge the considerable assistance given by many friends in the preparation of this paper.

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Obituary: Sir Ellis Hunter, G.B.E.

Sir Ellis Hunter, G.B.E., chairman of Dorman Long and Co. Ltd, died at his home in Yorkshire on 21 September. He was 69. Born at Great Ayton, Yorkshire, Ellis Hunter went to school in Middlesbrough, where he later entered an accountant's office. He qualified as an accountant in 1913, becoming F.C.A. in 1927. During the 1914-18 war he was with the Ministry of Munitions in a department concerned with iron- and steelworks extensions and profit control. His association with Dorman Long began in the 1930's when he took a major part in restoring the company after it had suffered severely during the trade depression. He became deputy chairman in 1938 and was later appointed managing director.

During the 1939-45 war Sir Ellis Hunter became closely associated with the British Iron and Steel Federation, and he was elected president in 1945. In his eight years of office, in close co-operation with the independent chairman of the Federation, Sir Andrew Duncan, he acted for the steel industry in one of its most critical periods, first producing a post-war development plan of great foresight, and later negotiating with the government, on behalf of the industry, throughout the period of nationalization. Although this work kept him frequently in London, he continued his close contact with Dorman Long in Middlesbrough, where the monthly directors' meetings were always held. While maintaining strong personal control of the company, Sir Ellis Hunter encouraged younger men in key management positions, and in 1944 he began a scheme of appointing special directors to the board. In March 1961 he resigned from all executive appointments in the Dorman Long group.

He was knighted in 1948 and advanced to Knight Grand Cross of the Order of the British Empire in 1961.

Stove design and performance

E. W. Voice

INTRODUCTION

IF BLAST TEMPERATURES of 3000°C were possible, and the blast-furnace would 'take' them, then fuel requirements for ironmaking would approach the theoretical minimum because all the top gas could be used in the stoves. While this target is nowhere in sight some operators already use 1000°C and contemplate 1200°C. Many more operators would like to raise present-day temperatures from, say, 700° to 900° or 950°C, a modest increase in duty of 20 or 30%.

Two main questions therefore arise:

- (i) how best to modify an existing installation to increase its duty
- (ii) how best to design the stoves in a new installation.

Neither question can be answered without a full understanding of all the problems and of the operation of stoves. Fortunately many people are now working on this subject, and it is to be hoped that real progress will soon be made towards this objective. Meanwhile this paper discusses some of the problems and bottlenecks in both the theory and operation of stoves.

HEAT BALANCES

A study of the overall heat balance of a stove system is useful because while it highlights much of importance it is immediately apparent that it does not tell the whole story. For example, the surface area of the checkers does not enter the heat balance equations and yet this must have an important effect on operation.

The blast-furnace requires the stoves to heat a given volume of air from the temperature of the cold blast to that of the hot blast. This 'duty' demands an amount of heat/min equal to the volume of air/min multiplied by the temperature rise and by the specific heat of air. This may be calculated precisely.

The gas burners must supply this energy plus the heat losses in the flue gas and any heat losses from the shell. Experience shows that the thermal efficiency of the stoves is usually in the range 75–90%, so there is little doubt about how much gas of a given calorific value must be fully burned to satisfy the required duty.

Depending on the number of stoves simultaneously on gas, the stove cycle time and the time for changing

SYNOPSIS

Heat balances between the hot blast requirement, the gas burned and the heat transferred per stove cycle are discussed. Heat transfer from combustion products to the brick and from brick to air depend upon temperature differences of gas and solid, heat capacity and conductivity of brick, gas velocities, shape factors, etc., and is extremely complex. Suggestions are made for different checkers which should prove better for modern and future requirements.

Gas burner ratings, air/gas ratios, etc., are discussed, and the need for greater intensity of combustion is stressed.

Stove performance today is mainly predicted from previous practice; a great deal of fundamental study plus refined mathematical techniques would be necessary to enable stoves to be designed from first principles.

Better refractories, different checker shapes, bigger burners and air fans, shorter cycles or different stove arrangements, together perhaps with higher pressure drops, can undoubtedly raise the performance of stoves considerably without the need of larger stoves. 2021

the valves, etc., the necessary burner rating, i.e. ft³ gas/min, can be calculated.

When on blast a stove will give up some of its heat and it must do this at the rate the blast-furnace requires. In so doing the average temperature of its brickwork will drop and this will depend on the number of stoves, the effective weight of the checkers, the stove cycle time, and the specific heat of the refractory. The numerical relationship of these quantities is shown in equation (1):

$$\frac{V \times T^{\circ}\text{C}}{27.8} = \frac{GR \times CV \times 'e'}{100} = \frac{N \times EM \times S \times \Delta T_B^{\circ}\text{C} \times n}{33}$$

or

$$\frac{V \times T^{\circ}\text{F}}{50} = \frac{GR \times CV \times 'e'}{100} = \frac{N \times EM \times S \times \Delta T_B^{\circ}\text{F} \times n}{60} \dots\dots(1)$$

Hot blast duty in Btu/ min	=	{ Heat from gas burnt minus heat losses	=	{ Summation of heat transferred from stoves to air
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where V =blast volume in ft³/min; T =temperature difference between blast and cold main; GR =average amount of gas burnt in ft³/min; specific heat of air taken as 0.02 Btu/°F/ft³; CV =calorific value of gas in Btu/ft³; 'e' overall percentage thermal efficiency of stoves; N =number of stoves; EM =effective mass of brickwork in lb/stove; S =specific heat of brick (typically 0.25 Btu/lb/°F); ΔT_B =average temperature

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difference of the effective brickwork between the end of the heating period and the end of the cooling period; n = number of cycles per stove per hour (cycle time includes on gas, on blast, bottled, and changeover times).

These formulae are useful in that any one quantity can be calculated if all the others are known and they show the dependence of the number of stoves, weight of checkers, stove cycle time, and ΔT_B on each other. They show, for a given value of ΔT_B , that, for example, doubling the frequency of stove changing means that the weight of checkers can be halved. They do not, however, tell a designer what value he should assume for ΔT_B or what checker design will, in fact, be suitable for any particular selection of these four variables.

HEAT TRANSFER

Heat is transferred from the combustion products to the brick and from the brick to the blast-furnace air, and these transfers occur at the brick/fluid surfaces. The amount of heat transferred per square foot of surface depends on the velocity of the gases, the shape and roughness of the surface, the temperature difference between brick surface and gases, the thermal conductivity of the brick, etc., and is altogether extremely complex. Depending on the stove arrangement, the rate may be greater or less when on gas than when on blast. With the normal arrangement of three stoves the rate of heat transfer is greater on blast and thus many designers pay more attention to this. An important point is that an overall rate of heat transfer is easily calculated and it is independent of complications such as cycle time, etc.

If Q = blast-furnace duty in Btu/min and A is the surface area per stove, then for normal operation of one stove on blast the overall rate of heat transfer on blast $\beta = Q/A$ Btu/ft²/min.

It is important to stress that this β is an overall rate and it would be wrong to assume that β is constant at every stove level or at all times.

From experience with modern stoves on blast, it is found that β is usually between 8 and 12; 8 representing a stove system which could be worked harder and 12, or even 14, representing a stove system doing reasonably well today. Because of this experience β is often taken as equal to 10 Btu/ft²/min for design purposes. Also most mathematical treatments of stove operation predict reasonably realistic performance (they would have been abandoned or modified if they did not) and so these too predict that β is around 10 Btu/ft²/min.

If, therefore, β can be accepted at this value then stove design is simple. Knowing the duty Btu/min required for the blast, it is divided by $\beta = 8$ or 10 Btu/ft²/min to give the surface area required per stove. Knowing the weight of checker per ft² of surface area to be typically 9–10 lb/ft², the weight of checker per stove in lb equals about the Btu/min required by the hot blast. As blast-furnaces become larger and temperatures become higher, then on this basis stoves become proportionally larger, and more expensive. With this overall heat transfer rate of 1 Btu/min/lb of stove brick and a specific heat of 0.25, $\Delta T_B = 4^\circ\text{F}$ multiplied by the time in minutes the stove is on blast. For 30 min on blast $\Delta T_B = 120^\circ\text{F}$, or for 1 h on blast $\Delta T_B = 240^\circ\text{F}$. The main point of this paper is to ques-

tion the apparent inevitability of this state of affairs. Certainly modern checkers as normally used in stoves operate with these values of β , and stoves designed on this basis operate to specification, but acceptance of these criteria would mean no improvements in checker design or stove operation.

What influences the value of β ? It is controlled mainly by:

- (i) the gas velocity in the checker flues
- (ii) the shape and size factor of the checker flues, i.e., the hydraulic diameter, surface roughness, etc.
- (iii) the temperature difference between fluid and brick surface and this presumably varies with position and time
- (iv) thermal conductivity and dimensions of brickwork to make available at the surface the heat stored within the depth of the brick
- (v) the duty performed for the blast-furnace and the checker design in that $\beta = Q/A$.

A value of $\beta = 10$ is thus a useful criterion for assessing the performance of different stoves, *each with today's checkers*. If, for example, an operator wants to rearrange his stove operation and calculations demand that some run at $\beta = 20$ or 30 Btu/ft²/min, then he can expect trouble. Markedly higher values can only be obtained with present checkers by decreasing blast temperatures or raising dome or stack temperatures to unacceptable levels. With replacement checkers there are three main approaches to increasing duty:

- (i) raise β by small flues and high velocities
- (ii) increase surface area of checkers per cubic foot of stove
- (iii) raise dome temperature by using better quality refractory.

It is believed that, for adequate improvement in performance, changes in all three are desirable.

Summarizing, therefore, while $\beta = 10$ is relevant to today's checkers, this particular value is meaningless and of no consequence if the checker is of markedly different design.

STOVE ARRANGEMENTS

There are three main methods of running stoves.

- (1) One on gas, one on air, two-stove system. With trouble on any stove the furnace suffers quickly.
- (2) Two on gas, one on air, three-stove system. The rate of burning gas per stove is halved, so that burners can be smaller and in the event of trouble the system can revert to a two-stove system. Because there is then only one stove on gas instead of two, the duty has normally to be reduced.
- (3) Two on gas, two on air in staggered parallel four-stove system. This interesting system was recently reconsidered by the Americans. There are still two on gas so the burner ratings are the same as for (2). If a stove is in trouble, then normal three-stove operation can be used to maintain the normal furnace duty, provided the cycle time is shortened.

In (1) and (2) cold air additions are made to the hot blast to dilute the hot air and so obtain air at a constant temperature at the furnace. In system (3) stoves

TABLE I Different stove arrangements to give same duty

No. of stoves	On air	On gas	Time On air	On gas	Relative stove height required	Relative stove checker installation	No. of stove changes per day
3	1	2	1	2	1	1	48
4	2	2	2	2	$\frac{2}{3}$	$\frac{2}{3}$	48
4	2	2	$1\frac{1}{2}$	$1\frac{1}{2}$	$\frac{2}{3}$	$\frac{2}{3}$	64
4	2	2	1	1	$\frac{1}{2}$	$\frac{1}{2}$	96
4	2	2	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{10}$	$\frac{1}{4}$	128

are left on blast after their temperature drops below the blast temperature, because the cooler stove supplies colder air in parallel to the hotter stove, thus maintaining a constant blast temperature without the use of the cold blast mixer main. The amount of air flowing through each stove varies continuously with time, and a new feature is that the overall duty (Btu/min) also varies with time. This variable duty in each stove complicates the mathematical analysis, and in practice nobody has published a satisfactory solution. When first put on blast, the hot stove supplies low air flows at high temperature to top up the temperature of the larger air flow from the cooler stove. As the cooler stove cools still further, its air flow rate is reduced and the flow from the hotter stove is increased until finally the hotter stove is down to blast temperature and the air flow through the cooler stove is reduced to zero.

In this operation the stove brickwork passes through double the normal temperature range, i.e. ΔT_B is doubled for given dome, stack, and blast temperatures. On one trial in America this was confirmed. The same four full-sized stoves were used to provide the same blast-furnace duty and so the cycle time had to be doubled to compensate for doubling ΔT_B .

To consider further the influence of stove operation, equation (1) has to be studied. Even with ΔT_B largely dictated by dome, blast, and stack temperature, there is considerable design latitude in terms of n , N , and EM , to ensure a given stove performance.

Table I shows the arrangements which would provide the same volume and temperature of hot blast at the same value of dome temperature.

To preserve the same number of changeovers, four stoves of half the normal height would be equivalent to three stoves and the total weight of brick would be $\frac{2}{3}$ normal.

By doubling the frequency of changeovers four stoves of $\frac{1}{2}$ height would have only $\frac{1}{3}$ the total normal weight. These very low stoves would call for modified checker design to preserve 85% thermal efficiency but would encourage replacing the stove combustion flue by a top high intensity burner.

The general validity of these relationships and the fact that ΔT_B is doubled by using four-stove staggered parallel operation to give a standard stove duty have all been verified experimentally using a laboratory set-up of small stoves.

MATHEMATICAL MODELS

This is the fashionable term used to describe a mathematical or electrical simulation of the physical phenomena occurring. Usually they necessitate the use of a computer because they attempt a more accurate description of the problem than is possible with a slide

rule or desk calculator. Even so all mathematical methods so far published make certain assumptions which may or may not be justified; this is because the functioning of a stove is extremely complex. While valuable advances can be made with these techniques, most mathematicians tend to be satisfied when they can describe today's performance with today's checkers, etc. Far too few are prepared to look into the unknown and to risk their reputation by predicting, for example, what checker design would be appropriate to achieve the conditions shown in the last line of Table I. Also, when calculations suggest, for example, a certain rise in blast temperature for a certain rise in stack temperature, it is important that the reader should be reminded of the assumptions made in the calculation. In addition, estimates of the temperature drops between flame, dome, top checker brick, blast at the stove outlet, and blast at the bustle main are still largely empirical.

GAS BURNER REQUIREMENTS

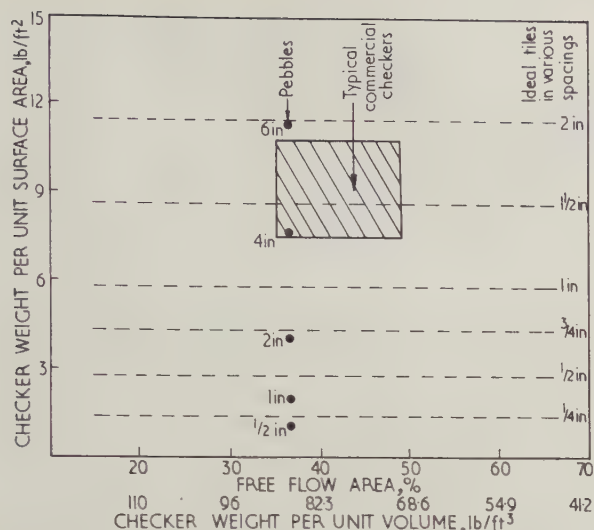
Equation (1) shows quite clearly the gas requirements for normal operation. For sustained operation this quantity simply must be burned. If the blast temperature or volume is to be increased, then first of all more gas must be burned. It is no good first increasing the height of the stove and then realizing that the increased pressure drop reduces the capacity to burn gas. By tradition, gas burners only partly mix the gas and air so that burners cannot overheat. The semi-mixed stream of gas enters the combustion chamber and is expected to use much of its vast height before combustion is complete. The result is that only 600 or 700 ft³/min of gas can be burned per ft² of combustion flue cross-section (say 6–8 ft³/min gas per ft³ of combustion chamber).

This is an extremely low intensity of combustion and is quite unjustified. Any increase in gas rate usually leads to pulsation and explosions. If adequately mixed, however, complete combustion would occur within one or two burner diameters; the combustion chamber would be evenly heated (no hot spots) and there would be no explosions. The maximum gas rate would be dictated first by acceptable pressure drops, and second, by the efficiency of heat transfer in the checkers. It would be considerably greater than today's normal limit.

Jones and Laughlin have shown by full-scale trials that the gas burned can be increased very considerably in this way and that the conception of a large combustion chamber is unnecessary.

COMBUSTION AIR REQUIREMENTS

It is not enough simply to pump gas into the stoves. There must be adequate air available to burn it completely and to reduce the flame temperature when necessary. Too many stoves have a simple fan which runs at constant speed throughout the gas period. On a recent stove study, it was found that the air fan passed about 200 000 ft³/h. With the blast-furnace gas analysis available, this gave a heating up gas rate of 240 000 ft³/h for the first hour or two. Once the dome temperature thermocouple reached the prescribed temperature of 2100°F, the operators could only: (a) reduce the gas rate to 170 000 ft³/h, or (b) increase the gas rate to 300 000 ft³/h.



1 Relative characteristics of various stove fillings

Both methods controlled the flame temperature as required but (a) reduced the gas input and therefore limited the available blast temperature, whereas (b) used excess gas as flame coolant, generated 8% or so CO in the waste gases but did generate heat equivalent to the complete combustion of 240 000 ft³ of gas per hour and thus maintain a high heat input rate. To obtain high outputs from today's stoves, it is essential that virtual stoichiometric conditions should be obtained during initial heating and that the air rate is then increased for flame, and therefore dome, temperature control; not the gas reduced.

Once the stack temperature reaches the prescribed limit the stove should be bottled. If it is found that the stoves are always bottled for part of the cycle then the duty, i.e. blast temperature, may be raised if required or the burner gas and air rate reduced throughout the gas period in order to improve slightly the thermal efficiency of the stoves.

CHECKER DESIGN AND PROPERTIES

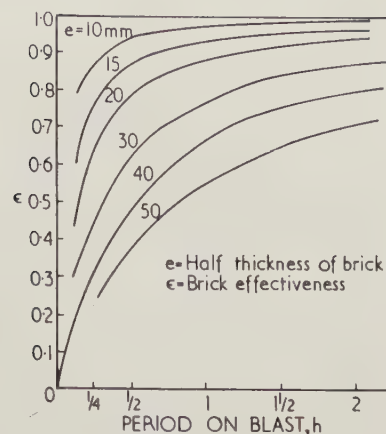
Figure 1 shows typical weights/ft² of vertical available surface area against free area of cross-section for checkers in common use. These are computed from available drawings assuming that the specific gravity of the firebrick is 2.2. In general, older designs are the higher weights and modern designs the lower weights. This is, of course, strongly influenced by gas cleanliness, but now that gas is so well cleaned is not a further reduction in weight per ft² possible?

The lower scale may also be expressed as weight of checkers per ft³ of stove, assuming no cross channels.

Round smooth pebbles could be used as checkers, so figures are included for them. It will be seen that pressure drops would be high because of the small free area of cross-section. Pebbles also suffer the disadvantage of point loading and this could be serious if deep beds were used.

Let us consider checkers in the form of tiles stacked vertically with various horizontal air gaps between them in order to get an idea of what sort of weights per ft² could ideally be achieved. If properly stacked there would be no increase in loading per in² compared with normal checkers.

2 Effectiveness of bricks of various thicknesses as a function of time on blast



If the tile is 1 in thick and the air gap is 1 in, then the free area is 50%, if the air gap is 2 in the free area is 66%, and so on. Figure 1 shows data plotted for different tile thickness and air gaps. It will be noticed that the wt/ft² surface area does not depend on the air gap, whereas the surface area (and weight) per ft³ of stove volume does of course depend on the spacing. For maximum duty from a given volume of stove, the gap should be small, giving a low free cross-sectional area and a high pressure drop. It is reasonable to assume that thin tiles or checkers will have a greater proportion of their mass effective than thick ones. Some designers claim that heat is fully available up to $\frac{3}{4}$ in penetration and that beyond this any mass has zero effectiveness. Clearly this cannot be right and in any case the effectiveness will depend on the cycle time.

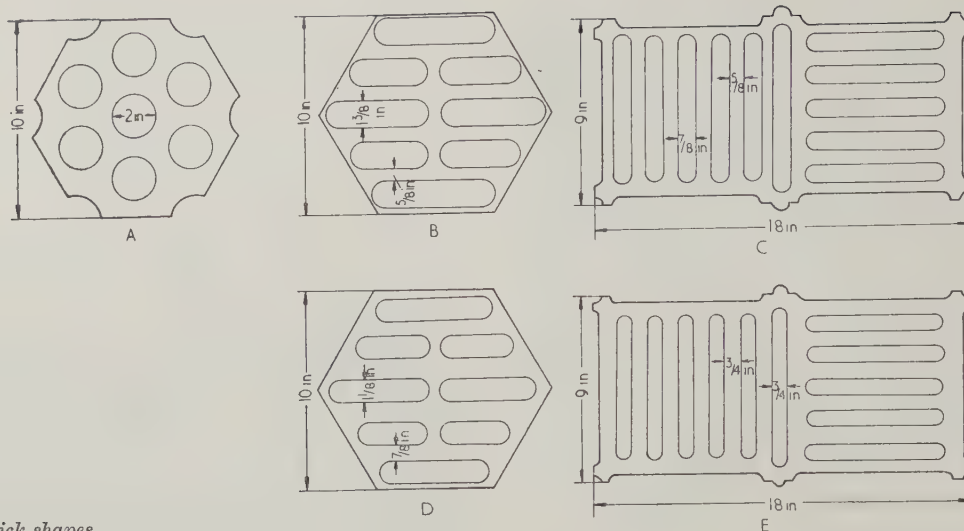
Sanna takes a more realistic approach to this question. He gives Fig. 2 for the effectiveness of normal checker firebricks.

This shows that with periods of 2 or 3 h on blast, $\frac{3}{4}$ in is reasonable as a half brick thickness, whereas for 30 min on blast the half thickness should not exceed $\frac{3}{8}$ in if 95% effectiveness is to be achieved.

Pressure drop across the checkers is of particular importance on the gas cycle, because there is seldom pressure to spare, whereas on the air period a few extra inches pressure drop hardly affects the blast pressure. When comparing different checker designs for pressure drop it is not enough to look only at the % free cross-section area. A given area may be in the form of many thin slots, fewer wider slots, or as many square or round holes, and pressure drops will vary widely for these arrangements. Attempts to calculate pressure drops for specific shapes have not been very successful because the result depends largely on which book is consulted. With a knowledge of pressure drops for normal checkers, however, it is possible to obtain a reasonable estimate for a new shape, provided it is not too different from the normal.

TRENDS IN STOVE PERFORMANCE

With an installation operating with a large margin between dome temperature and blast temperature, the operator can usually increase blast volume or blast temperature at will. Often he comes up to a limit in gas burning so that a further increase in temperature can only be obtained at the expense of a reduction in



3 Checker brick shapes

blast volume. At this stage the next requirement is to burn more gas by modifying the burners or air fans or by modifying the stove system to reduce the time that the burners are off. Cycles may be shortened if the stoves are ever bottled or mechanical valve changing adopted to reduce changeover times.

Raising the dome and stack temperature helps and this is usually done to the limit of safe and economical operation. If still higher temperatures are required, then more surface area of checkers is necessary.

In order to gain an extra 50°C on blast temperature it may be necessary to increase considerably the surface area of checkers. To install extra checkers to achieve this is much more expensive than to design a checker with the extra surface in the same brick volume. Four-stove operation would also help, but operators are surprisingly unenthusiastic about this.

Because of changing blast-furnace requirements, improvements in refractories and the personal preferences of operators, different approaches will be taken. As time goes on the stove will operate nearer and nearer to the limit in terms of blast and dome temperatures. Unless there is a new look into the question of optimum design of checkers (wt/ft³, wt/ft², permissible pressure drop, etc.), then stoves will become even larger than the extravagant size and cost they are today.

RECOMMENDATIONS

Burners

Bigger, better burners, which ensure rapid combustion are a first necessity so that there is no bottleneck on heat input. Stove installations should have adequate burners so that when one stove is down the others can supply the full furnace gas requirement. If the operator demands this he could have it at the price of shorter cycle times when in trouble. This should be acceptable with mechanized or automatic stove changing.

New installations

The second, third, and fourth lines of Table I should be seriously considered. Tile checkers with tiles $\frac{1}{2}$ in thick, spaced $\frac{1}{2}$ in apart would weigh 68.6 lb/ft³ (specific

gravity 2.2). They would have 24 ft² surface area per ft³, i.e. wt/ft²=2.8 lb.

Taking line 2 of Table I, stoves of half height would, with these checkers, operate at a maximum $\beta=7$ Btu/ft²/min compared with the normal 10 for the same duty, and the pressure drop would be less than normal because of the reduced height. Undoubtedly this installation would have far more capacity in blast temperature and blast volume than a classical three-stove operation, yet the weight of brick would be only $\frac{2}{3}$ normal.

These, or thinner, tiles with narrower spacings could finally be used to achieve the performance shown in line 4 of Table I.

Recheckering existing installations

While the above represents a drastic change in checker and stove design, it is important to decide what sort of checker to use to replace those in an existing installation.

Choosing higher temperature materials in the normal shapes will enable higher dome temperatures, and therefore higher blast temperatures, to be obtained. The higher blast temperature means, however, a higher duty and a larger value for β so that the blast temperature cannot approach the dome temperature as closely as it would if the surface area were simultaneously increased appreciably.

If, after recheckering, the duty is to be increased by 15 or 20%, then clearly the gas rate must be increased correspondingly, and the pressure drop (on gas) across the checkers will increase by 30 or 40%.

TABLE II Properties of bricks shown in Fig.3

Shape	Wt/ft ³ surface area, lb	Wt/ft ³ stove, lb	Surface area, per ft ³ stove, ft ²	Relative pressure drop at same gas rate
A	9.90	85.1	8.59	1
B	5.00	60.6	12.12	0.7
C	4.18	67.6	16.17	0.7
D	6.75	77.4	11.46	1
E	5.10	76.9	15.07	1

Figure 3 shows the basic dimensions of:

- (A) typical normal checkers
- (B) and (D) possible replacement checkers having substantially greater surface area, yet able to pass 15 or 20% higher gas rate for the same pressure drop as at the normal gas rate for the normal checker (A). The weight per ft³ of stove volume is down, necessitating slightly shorter cycles.
- (C) and (E) possible replacement checkers having pressure drops and weight/ft³ comparable with the normal checker (A), but with substantially greater surface areas.

These sketches are intended to show possible lines along which development should occur in checker design.

Table II shows the relative weights, areas, etc., for the shapes shown in Fig.3 assuming the specific gravity of the bricks is 2.2.

CONCLUSIONS

1. To increase the duty of a stove it is usually first necessary to increase the gas rate and the air for combustion and flame temperature control.
2. Only when these are known to be adequate should any change in the checker design be contemplated.
3. New top checkers should be constructed from the best high temperature materials so that higher dome temperatures can be tolerated. Improved checker design having a lower weight per ft² of surface area should be incorporated to achieve the highest possible temperatures of blast within any given dome and stack temperature limits.
4. Four-stove operation with appropriate checkers should be developed to reduce the bulk of stoves for any given duty.
5. Better mathematical techniques are needed to predict stove performance with fewer assumptions. More precise heat transfer and pressure drop coefficients are required for new designs of checkers.

Increase in productivity of blast-furnaces operating on mixed ore burdens

Jean Boland

OUTLINE OF BURDEN PREPARATION AT OUGREE

ALL THE ORES pass through two gyratory crushers. According to the type of ores, after crushing there remains 10 to 15% of pieces greater than 50 mm (from a test on screen with 50-mm dia. holes).

The size gradings of the two ores which form the major part of the charge are shown in Fig.1 (before crushing), and in Fig.2 (after crushing).

The 0-10 mm fraction is eliminated by electrically-heated screens and goes to the sinter plant. The 10-50 mm fraction is taken to the blast-furnaces. The 10-50 mm ores may be separated into the two sizes by means of a rod-deck screen; because of the lack of bunkers, we have been unable to carry out this separation to date.

At the sinter plant, the raw mix is controlled by constant weight feeders on the conveyor belt. The sinter produced by an 8in Dwight Lloyd machine is screened to +10 mm before it reaches the forced air cooler; the hearth layer consists of 0-15 mm material from the cold screening of a small part of the sinter. The coke is crushed by two grooved-roll crushers.

The ore and sinter analyses are shown in Table III(1). The average size analyses of crushed coke and sinter before charging into blast-furnace are shown in Table III(2).

SYNOPSIS

The blast-furnaces of the Ougrée works (SA Cockerill-Ougrée) have a mixed burden composed roughly of 50% Swedish ores and 50% French ores from the Briey basin. Crushing lower than 50 mm with sintering of 0-10 mm fines has enabled the driving rate of the blast-furnaces to be increased by 21%, while decreasing the coke rate by 36%. The combined influence of both these factors increases the productivity by 65%. The sulphur content of the pig iron has strongly decreased: 75% of the samples contained less than 0.035% S. The results given were obtained in blast-furnace 5 of the Ougrée works. Throughout the tests, the operating conditions were kept constant in order to obtain valid results. The difference between the results of the first trial in September 1960, and those of the second in May 1961, should be emphasized. The improvement is mainly due to improved distribution of the gases in the stack, an improvement which was brought about after systematic analysis of the gases in the stack. 2008

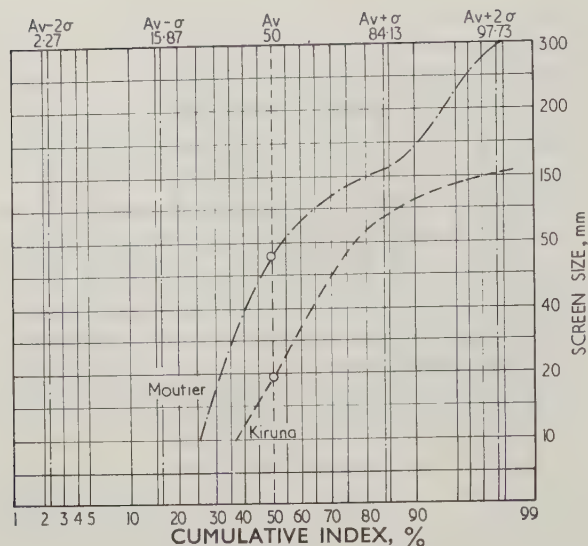
Trial conditions

We chose no.5 blast-furnace (blown-in in August 1959) as being the newest at the Ougrée plant. Its profile is shown in Fig.3.

During the three periods, we kept the operating conditions constant so that the average results would

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1 Size gradings of run-of-mine ores: Ougrée blast-furnaces

be of full value. In Table I, we show the composition of the burdens for the three periods. In Table II, we have reconstituted the burdens with run-of-the-mine ores so as to facilitate comparisons between the results of the three periods.

Choice of operating periods

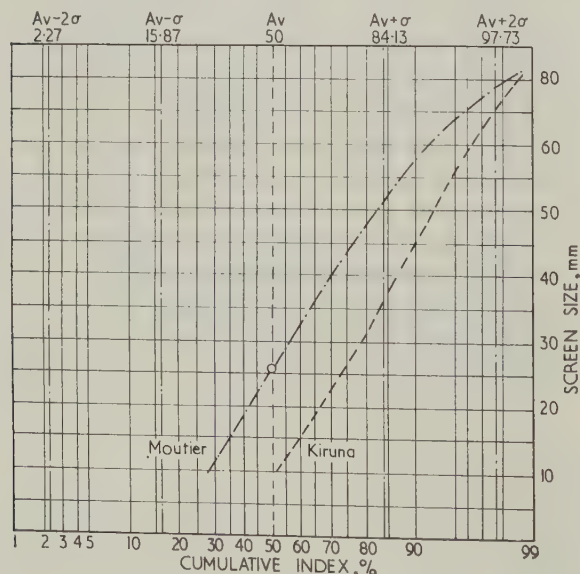
Crushing and screening the ores started in May 1960. The sinter plant started up on 17 June 1960.

April 1960 was the last month when no.5 blast-furnace was operated on unprepared ores. The maximum blowing rate was used and the descent was very irregular. If the volume of the blast was increased, flue dust became too high and the working of the blast-furnace too irregular.

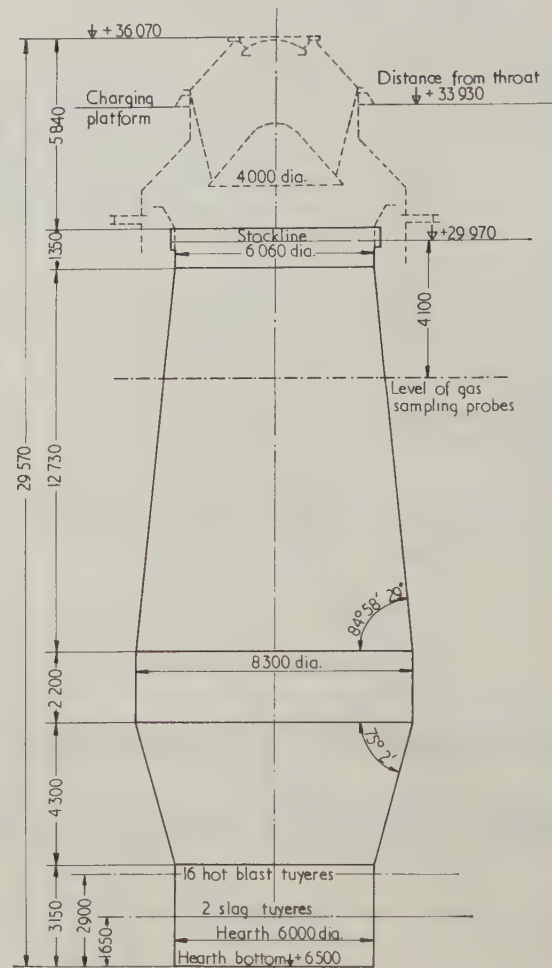
September 1960 was the first month when the ores were completely prepared.

May 1961 was the last month of working we could record before drawing up this paper.

We took the results of September 1960 and May 1961 in order to show the benefit which could be



2 Size gradings of crushed ores



Dimensions in cm

3 Profile of Ougrée blast-furnace no.5

obtained from a few months of adjustment: better screening of ores, better operation of the sinter plant, and above all an improved performance of the blast-furnace as a result of better distribution of the charge.

Examination of these three periods shows a spectacular drop in coke rate of 215 kg since the charging of the prepared burden, and shows also that it is still possible to save 40 kg of coke by carefully following the operation of the sinter plant and the blast-furnace.

As the value of the correction coefficients is sometimes debatable among blast-furnace operators, it

TABLE I No.5 blast-furnace: Raw materials

	April 1960 %	September 1960 %	May 1961 %
Moutiers	18.7	16.6	11.0
Baroncourt	1.6	13.3	17.2
Bouigny	17.9	...	...
Kiruna D	33.9	14.9	8.2
Kiruna C2	...	...	5.4
Norwegian	...	2.4	...
Gellivare	16.5	5.8	5.4
Millscale	3.3	2.3	0.3
Limestone	3.2	3.6	2.7
Miscellaneous	4.8	1.2	4.6
Scrap	0.1	0.1	0.1
Sinter	...	39.8	45.1
Total	100.0	100.0	100.0

TABLE II No.5 blast-furnace: burden expressed as run-of-mine ores

	April 1960 %	September 1960 %	May 1961 %
Moutiers	18.7	27.3	18.5
Baroncourt	1.6	22.8	27.8
Boulogny	17.9	...	...
Kiruna D	33.9	24.4	15.5
Kiruna C2	...	...	...
Norwegian	...	3.8	...
Gellivare	16.5	13.4	18.3
Millscale	3.3	2.4	2.2
Limestone	3.2	4.0	2.7
Miscellaneous	4.8	1.8	4.8
Scrap	0.1	0.1	0.1
Total	100.0	100.0	100.0

should be noted that we have given the gross results with all the working conditions. These are sufficiently explicit to enable the results obtained to be brought down to standard temperature conditions, weight of burden, etc.

Analysis of working characteristics

Operating data (Throughout the paper 'ton' indicates the metric ton, here abbreviated 't')

	April 1960	September 1960	May 1961
Iron production, t/24 h	495	708	815
Coke consumption, t/24 h	478	531	578
Coke rate, kg/t iron	965	750	709
Net iron content of burden, %*	45.9	46.5	47.3
Slag volume, kg/t iron	618	676	671
Net burden wt, kg/t iron*	2180	2146	2116
Flue dust make, kg/t iron	131	58	33
Blast pressure, cm Hg	55.9	64.9	72.2
Blast temp. in the hot blast main, °C	811	798	838
Top gas temp., °C	319	159	179
Coke burning rate, kg coke/m ² /h	706	783	852
Slag basicity, i=CaO/SiO ₂	1.46	1.43	1.43
Iron analysis, %			
Si	0.290	0.320	0.400
S	0.043	0.025	0.027
Mn	0.750	0.750	0.800
C	3.550	3.700	3.650
Coke analysis, %			
H ₂ O	1.22	1.65	1.08
C	88.27	88.15	88.79
	9.62	9.30	9.26
	0.89	0.90	0.87
Top gas analysis, % vol.			
CO ₂	9.1	12.3	13.3
CO	31.6	28.3	27.7
H ₂	2.3	2.1	1.8
N ₂	57.0	57.3	57.2
Calorific value, kcal/N m ³	1014	909	883
Indirect reduction, %†	54.45	58.78	61.7
Charging cycle	CC/OO/CC	CO/CC/SO	OC/SC/CO
		/CS	/SC/OC/CS
Error on iron balance, %	+1.4	+2.1	+2.7

* Corrected value for flue dust loss

† %, indirect reduction = $\frac{\text{Wt CO}_2 \text{ in gas} - \text{wt CO}_2 \text{ in ores}}{\text{Wt CO}_2 \text{ produced if all oxides of iron were reduced by CO}}$

For the three periods, the error in the iron balance is in the region of +2%.

Production of pig iron

The increase is due to a higher driving rate of the blast-furnace (+21%), and at the same time a decrease in the coke rate (-36%). The combined influence of these two factors increases the productivity by 65%.



Sulphur content; 0.001

1 May 1960 burden: Briey 36.6%, Swedish 52%; 57% Briey crushed and screened

2 June 1960 burden: Briey 39.9%, Swedish 46.8%; 84% Briey and 6% Swedish crushed and screened

3 July 1960 burden: Briey 30.4%; Swedish 40%, sinter 26%; 94% Briey and 77% Swedish crushed and screened

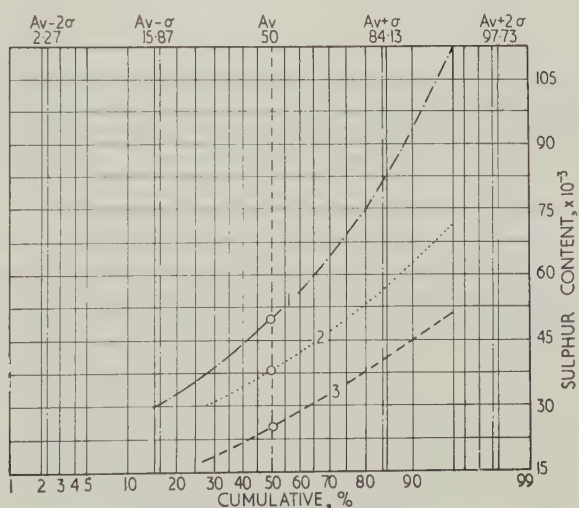
4 Blast-furnace no.5: monthly averages of S analysis of iron

Coke rate

This has decreased by 36%. We will refer to this again when examining the thermal balances.

Driving rates

It has been possible to increase the daily consumption of coke by 21%. For each period, the blast-furnace was extended to a maximum compatible with acceptable working results. In May 1961, we reached the limit of the capacity of the charging equipment. We are still of the opinion that the driving rate could be increased even more, without incurring depreciation of the coke rate.

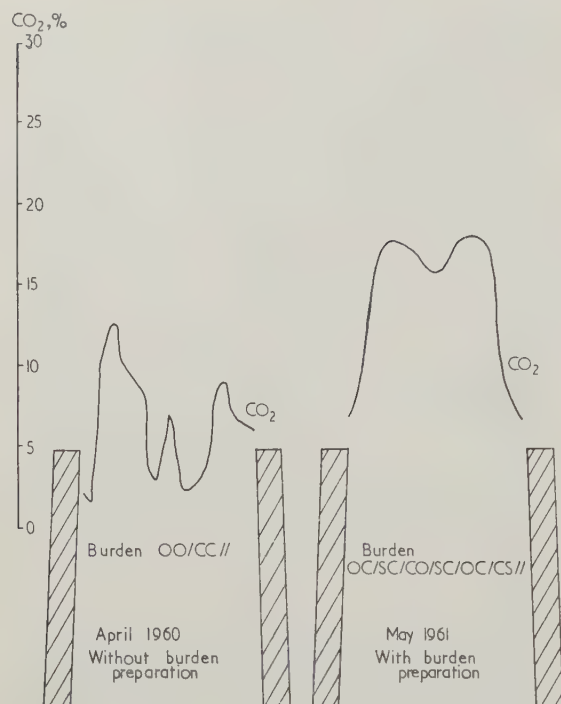


1 before burden preparation 495 samples

2 a part of the ore is crushed and screened 258 samples

3 with burden preparation 517 samples

5 Blast-furnace no.5: S content of pig iron



Level of probe: 4.1 m below stockline

6 Blast-furnace no. 5: gas sampling

Production of flue dust

From April 1960 to September 1960, the flue dust make decreased from 131 to 58 kg/t of iron, which is easily explained by the crushing of Briey ores, with the consequence of a reduction in the breaking-up of these ores in the blast-furnace stack.

From September 1960 to May 1961, the production of flue dust again decreased from 58 to 33 kg/t of iron despite the increased driving rate. This is undoubtedly due to better distribution of the loads at the stock line and to more regular distribution of the gases in the stack as is shown in Fig. 6.

Pig iron analysis

The sulphur content has substantially decreased. Figures 4 and 5 show the evolution of the sulphur content with the development of the preparation of the burden. This is easily explained by the decrease in the S content of the charge (desulphurization of the ores on sintering and decrease in sulphur as a result of the decrease in the coke rate).

It would appear that the C content in the iron has increased by about 0.1%, although this has not been noticed consistently at all the blast-furnaces. The higher Si content is the result of a request from the steelworks.

Analysis of the gas

From April 1960 to September 1960, the CO₂ content of the gas increased by 3.2%, despite the removal of carbon dioxide from sintering. The increase in the indirect reduction owing to the decrease in size of the lumps of ore explains these CO₂ contents.

During this period, the degree of indirect reduction increased from 54.45% to 58.78%.

From September 1960 to May 1961, after the insertion of gas probes into the stack, we modified the charging cycle and the diameter of the tuyeres. The consequence was better gas distribution in the stack; the CO₂ content increased by a further 1% and the degree of indirect reduction increased from 58.78% to 61.7%, indicating an increase in reduction by CO.

Thermal balance

Heat balances (Figures in untitled columns expressed in 1000 kcal/t of iron)

In	April 1960 kg C	September 1960 kg C	May 1961 kg C
Combustion of carbon to CO ₂	145.9	1141.4	161
Combustion of carbon to CO	663.0	1447.3	454
	808.9	2588.7	615
Sensible heat in moist blast	769.8	562.9	557.3
Sensible heat in burden	9.8	8.8	8.6
Heat of formation of slag	77.2	84.5	83.8
Heat of formation of Fe ₃ P	23.4	22.5	20.8
Total	3468.9	2929.3	2902.5
Out			
Heat of reduction of oxides	1593.1	1629.1	1620.3
Sensible heat of iron	295.0	295.0	295.0
Sensible heat of slag	262.6	287.3	285.2
Sensible heat of gas (including vaporization of water)	518.0	229.2	236.1
Sensible heat of flue dust	8.3	1.7	1.2
Reduction of H ₂ O	101.5	40.5	28.9
Decomposition			
Carbonates			
Hydrates			
Phosphates			
	219.5	180.5	161.8
Total	2998.0	2663.2	2628.5
Differences	470.9	266.1	274.0
Heat losses, errors, etc., %	13.5	9.1	9.5

Examination of the thermal balances for the three periods shows that the benefit from the preparation of the charges has important results.

(a) *Better use of coke* 3200 kcal/kg of carbon were needed in April against 3800 kcal in May 1961. The increase of indirect reduction is notable because of the smaller size, and an improved distribution of the gases in the stack as a result of more homogeneous sizing. The increase in indirect reduction from 54.45% in April 1960 to 61.70% in May 1961 shows this improvement well.

It should be noted that from September 1960 to May 1961, we have carried out systematic analyses of the gases in the blast-furnace stack. Two cooled and diametrically opposed horizontal probes are gradually inserted into the centre of the blast-furnace at a level situated at 4.1 m beneath the charges. Examination of the analyses of each gas sample, of the temperatures in the stack, and of the temperatures of the top gas, enables the distribution of the gases in the stack to be estimated. The charging may then be corrected by modifying the cycle, and the combustion zone modified by changing the diameter of the tuyeres.

In April 1960 (with unprepared burden), a tuyere diameter of 150 mm and a charging cycle CC/OO/CC gave the best results.

TABLE III Average analyses and size gradings

1 *Average analyses of ores and sinters (dry basis)*

	Moist.	Fe	Fe ⁺⁺	Fe ⁺⁺⁺	SiO ₂	CaO	S	P	CO ₂	H ₂ O (comb.)	degree of oxidation*
Moutiers	7.63	27.13	6.47	20.66	8.72	21.00	0.105	0.62	18.71	5.07	
Baroncourt	8.53	33.73	6.43	27.30	8.06	14.56	0.119	0.73	14.49	6.63	
Boulogny	8.60	32.20	7.10	25.10	7.83	16.05	0.093	0.64	16.44	6.20	
Kiruna D	0.46	59.90	19.53	40.37	3.63	5.89	0.024	1.62	0.74	0.23	
Gellivare	0.48	57.20	17.55	39.65	9.70	3.36	0.049	0.76	0.60	0.30	
Norwegian	0.40	52.50	12.40	40.10	11.94	5.50	0.040	1.09	0.34	0.80	
Kiruna C2	0.80	65.20	21.70	43.50	2.90	2.68	0.039	0.50	0.90	0.40	
Sinter (Sept. 1960)	0.32	52.60	13.20	39.40	8.54	9.49	0.016	1.10	0.48	0.10	91.64
Sinter (May 1960)	0.20	54.00	11.50	42.50	7.34	8.47	0.012	0.98	0.31	0.40	92.90

* $\frac{\text{O}_2 \text{ in sinter}}{\text{O}_2 \text{ if all present as Fe}_2\text{O}_3}$

2 *Average size grading*

Crushed coke mm	%	Sinter before charging to blast-furnace	
		mm	%
+5	1.5	+60	11.2
3-5	12.9	50-60	6.6
2-3	22.8	40-50	7.4
1-2	22.3	30-40	11.4
0-1	40.5	20-30	13.6
		10-20	22.0
		5-10	17.0
		0-5	10.8

In September 1960 (with prepared burden), we provisionally adopted the cycle CO/CC/SO/CS which gave a stimulus to the centre of the blast-furnace. Unfortunately we were delayed for two months by the strike which occurred in Belgium.

In April 1961, we reduced the diameter of the tuyeres to 120 mm and we adopted the following charging cycle: OC/SC/CO/SC/OC/CS.

The curve to the right of Fig.6 shows that the gas distribution is satisfactory. It should be noted that no.5 blast-furnace is charged by Stähler buckets, 10 m³ in capacity, and that this system limits the possibilities of distribution of charging at the throat. It is possible that even better results could be obtained with a McKee type top. This systematic study has nevertheless enabled us to save 40 kg of coke/t of iron with the equipment we have available for no.5 blast-furnace.

(b) *Decrease in gas temperature* From April 1960 to May 1961, it was noticed that the temperature of the gas had decreased from 319° to 179°C; this decrease, in conjunction with a reduction in the volume of the gas, as a result of the elimination of CO₂ in sintering and the decrease in the coke rate, enabled the heat loss at the furnace top to be brought down from 518.0 to 236.1 × 10³ kcal/t of cast iron.

(c) *Enrichment* The 0-10 mm Briey ores were enriched by elimination of the CO₂ of the carbonates by means of a cheap fuel during sintering, which obviated this operation in the blast-furnace stack and allowed a smaller charge to be heated more quickly.

(d) *Decrease in thermal losses at the walls* For a given blast-furnace having a suitable driving rate, the hourly thermal losses at the walls vary little. The preparation of the burden makes possible a higher productivity of the blast-furnace as a result of a burden of small and homogeneous size and of the enrichment of certain ores on sintering. The thermal losses by the walls have therefore clearly decreased per ton of iron.

CONCLUSIONS

In our case, it can be said that the gain from the preparation is the result of better gas-solid contact due to the crushing of the ores and the enriching of the Briey ores as a result of the sintering of the fraction 0-10 mm. There are, therefore, two distinct causes.

The preceding results show that crushing to a sufficiently small size (40-50 mm), followed by the elimination of the fines (0-10 mm), and by the sintering of these, results in such a decrease in the coke rate that the operation is always advantageous. The further decrease in the coke rate which could be obtained by crushing and sintering all the ores becomes small in comparison with the decrease of 256 kg which we obtained, and this gives rise to the following question: 'How far can the crushing and sintering of the ores be increased?'

Rather spectacular results, from the technical point of view, from working at 100% sinter must not cause the economic aspect of the problem to be forgotten. In May 1961, the energy requirements of the sinter plant were:

Per t of blast-furnace sinter	
Coke-oven gas	7.3 m ³ at 3850 kcal/m ³
Crushed coke	77.0 kg at 70% carbon
kW	20.8

We think that it will be difficult to decrease these figures still further; they represent expenses which, added to the maintenance and capital charges, are far from negligible. We do not think that working with 100% sinter would be advantageous in all cases.

From the examination of the results obtained at Ougrée and in other works, we think that, in future, the rich, reducible ores (hematites) should be crushed to a size of about 50 mm; the rich ores which are not easily reducible (Kiruna type) to about 25 mm, so as to obtain a better gas-solid contact; and the lean ores (hydrated and carbonated) should be completely

crushed and sintered in order to enrich them and thus diminish the thermal load of the blast-furnace.

The difference between the price of the coke and the cost of sintering (which is mainly a question of the relative costs of fuel) will be a determining factor in the choice of the size of crushing or of the total crushing of the ores, if this is adopted.

Whatever the ore, it is always necessary to eliminate the fines in order to obtain regular distribution of the gas in the burden, if the productivity is to be increased without detriment to the cost of the iron.

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The use of a computer in heat-transfer studies

M. S. Rhodes

INTRODUCTION

MANY PROBLEMS OCCUR in the field of heat transfer where the mathematics involved is not particularly complicated when treated in a purely theoretical manner; but when an attempt is made to evaluate, numerically, some of the expressions and functions involved, the resultant operations become extremely laborious, even when an automatic desk calculator is used. In some cases the mathematical method may not be particularly good, but its failings can only be revealed, probably in the form of acute loss of accuracy, by repeated use. Finally there may be so many numerical quantities to be dealt with that it is all too easy to leave out some portion of the calculation, thus leading to errors.

These are only a few of the reasons why the use of an electronic digital computer for some aspects of heat-transfer work is both desirable and necessary to enable accurate and reliable results to be provided. The following three studies show how this reasoning was applied to practical cases.

EVALUATION OF VIEW FACTORS

A view factor, from surface 1 to surface 2, referred to as F_{12} , is the proportion of radiation leaving the first surface which arrives at the second surface. It is dependent solely upon the geometry of the two surfaces concerned, and the absorptivity of the intervening medium. For a uniform absorption coefficient and plane surfaces, the integrations which have to be performed are sufficient to give the view factor F_{21} in addition to the view factor F_{12} . Obviously view factors may be required for an infinity of pairs of surfaces, and if any use is to be made of working to a fixed procedure

SYNOPSIS

This paper encompasses three studies of problems in heat transfer, use being made in each case of an electronic digital computer. The first is concerned with the evaluation of heat-transfer view factors between infinitely long plane walls separated by an absorbing medium. The second problem is the evaluation of the temperature lag between the centre and the surface of a furnace brick, when all the surfaces are experiencing a linear rise in temperature. The third study is the solution of non-linear simultaneous equations of the type occurring in radiative and convective heat transfer.

1978

as in the program of a digital computer, then the resultant procedure will be enormously elaborate and complicated, unless the surfaces are to be classed into separate groups, each with its own procedure. In the work described here, the surfaces treated are infinitely long plane walls, that is they are representative of a two-dimensional treatment of a three-dimensional physical case, e.g. an open-hearth furnace. This class has been further subdivided into parallel and non-parallel walls.

The basic integration to be performed is that arising from radiation between two infinitesimally wide, infinitely long strips. This yields an integral of the form:

$$\int_{-1}^1 e^{-kh/\cos\pi v} \cos^2\pi v \, dv$$

which is easily recognized as being incapable of analytic integration for non-zero values of kh . This has then to be further integrated (twice) to make both strips of finite width. To complete even one whole calculation, using a desk machine, would be most tedious and, since a number of these view factors

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would be required, it was decided to program the calculations for the company's Ferranti Pegasus computer.

Some method of numerical integration or quadrature had to be decided upon, and it was known that a Ferranti Pegasus computer subroutine was in existence for Gaussian quadrature, complete with up to 16 coefficients and corresponding abscissae. It was decided to go ahead with its use, and the mathematical treatment of the integration, on paper, was so devised that it was in a form acceptable for the computer. In the main, this entailed linear transformation for the variables such that the limits of integration were equally spaced about a fixed value, and differed from this value by an amount less than 1.0. This is already satisfied by the integral, already given, for the strip radiation. The resultant complete integrals were as follows:

For parallel walls:

$$J = BCX^2 \int_{-\frac{1}{2}}^{\frac{1}{2}} dt_2 \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{dt_1}{h^3} \int_{-\frac{1}{2}}^{\frac{1}{2}} e^{-kh/\cos\pi v} \cos^2\pi v \, dv$$

$$= B.F_{12} = C.F_{21}$$

$$\text{where } h^2 = X^2 + (Y + Ct_2 - Bt_1)^2$$

B = width of wall 1 (L)

C = width of wall 2 (L)

X = separation of walls (L)

Y = offset of wall centres (L)

k = absorption coefficients (L⁻¹)

For non-parallel walls

$$H = B^2 C^2 \sin^2 \alpha \int_{\frac{Y}{C} - \frac{1}{2}}^{\frac{Y}{C} + \frac{1}{2}} dt_2 \int_{\frac{X}{B} - \frac{1}{2}}^{\frac{X}{B} + \frac{1}{2}} dt_1 \int_{-\frac{1}{2}}^{\frac{1}{2}} \frac{dt}{h^3} e^{-kh/\cos\pi v} \cos^2\pi v \, dv$$

$$= B.F_{12} = C.F_{21}$$

$$\text{where } h^2 = (Bt_1)^2 + (Ct_2)^2 - 2Bt_1Ct_2 \cos \alpha$$

B = width of wall 1 (L)

C = width of wall 2 (L)

X = distance between (projected) corner and centre of wall 1 (L)

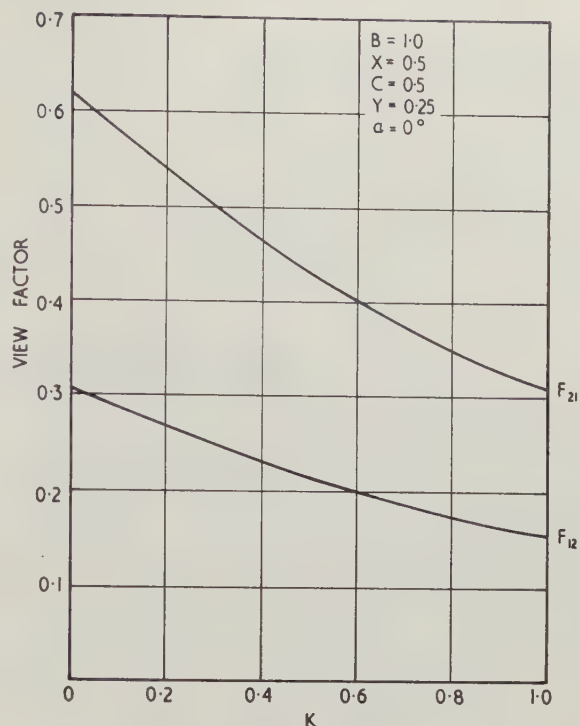
Y = distance between (projected) corner and centre of wall 2 (L)

k = absorption coefficient (L⁻¹)

α = angle contained by two walls

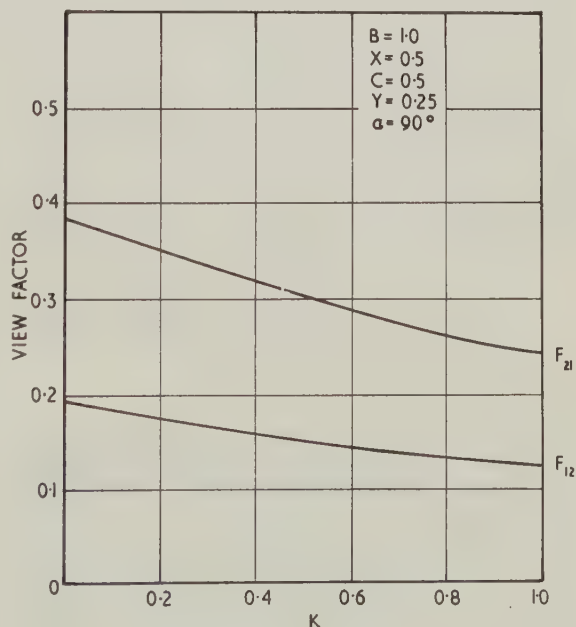
In order to obtain reasonable accuracy it was decided to use the 16-point program. This, however, involves the calculation of the integral for the v -integral some 2048 times and if some saving can be made here it will be very valuable.

If the v -integral is obtained for a wide variety of values of the product 'kh', and the results plotted against 'e^{-kh}', the resultant line is gently curved. Use of a curve-fitting program, written by a colleague, showed that the v -integral could be expressed as a power series in 'e^{-kh}' of six terms, sufficient to give six decimal-figure accuracy. The number of machine orders necessary to evaluate the integral in this power series form is much less than the number necessary for the previous method, and these are used only one eighth as many times. The resultant saving in time was as much as 80%, giving a final calculation time of just over 2 min. Examples of the results are shown in Figs. 1 and 2.

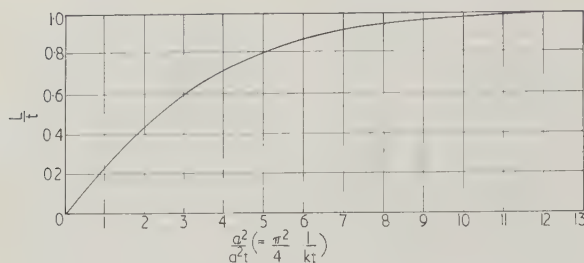


1 Variation of view factor with absorptivity, parallel walls

While the techniques already described were being finally developed, some of the ground was being covered again with the accent upon being able to provide results at earlier stages in the calculation. At the same time it was decided to use a much simpler form of integration, by trapezoidal rule. This is more crude, in general, than Gaussian quadrature, but it was felt that the greater simplicity of the internal working of the program would outweigh the main disadvantage of having to use a much smaller interval for use in the summation. This in fact was so, although at this stage



2 Variation of view factor with absorptivity, non-parallel walls



3 Variation of L/t with parameters α , α^2 , t , or k

it is not possible to obtain a figure to compare with the 2 min quoted previously, because this stage has not yet been reached.

Throughout most of the original program it was necessary to use floating-point representation of the numbers involved, since the input quantities could be of almost any size. Pegasus works in fixed-point representation and the conversion to floating point has to be made via programmed arithmetic. For the majority of the later programs, due to the method of representation of the physical conditions, it was possible to remain in fixed point working. This added to the simplicity of operation, and to the improvement over earlier methods.

What has been shown here is that having once determined the mathematical problem, there is much work to be done to translate it into a form acceptable by the computer, the translation from mathematical integrals to numerical summations. Later it was shown that there is much to be gained from using a simpler program, much more often, to gain accurate results without the use of excessive computer time.

EVALUATION OF TEMPERATURE LAG IN FURNACE BRICK

Where a block of refractory material is heated at its surface, such as a furnace brick, it takes some time for the rise in temperature to be transferred to an interior point. The way in which the temperature at some interior point lags behind the surface temperature can be written down mathematically. It does, however, yield a rather cumbersome looking expression, but by choosing a suitable interior point, and suitable dimensions, the expression may be simplified. For a cube of side 2α , made from material with thermal diffusivity α^2 , heated linearly at all its surfaces for a time t , all units being consistent, the lag (L), per unit heating rate, between the centre and the surface is given by:

$$L = \frac{64}{\pi^3 k} \sum_{n=0}^{\infty} \sum_{r=0}^{\infty} \sum_{s=0}^{\infty} \frac{(-1)^{n+r+s} (1 - e^{-ktA})}{(2n+1)(2r+1)(2s+1)A}$$

$$\text{where } A = (2n+1)^2 + (2r+1)^2 + (2s+1)^2$$

$$k = \pi^2 \alpha^2 / 4\alpha^2$$

Such an expression is rather cumbersome to evaluate by manual methods, for $n, r, s > 2$, and once again it was decided that the evaluation of the expression would be programmed for the computer. Two slight simplifications were made. Both sides of the above equation for L were divided by t , thus making the quantity L/t a function of kt . The term $(1 - e^{-ktA})$ inside the triple summation signs may be split into two, only one of which is dependent upon kt . The

other may be combined with the remaining terms in the triple summation, and evaluated once only.

Very little else has to be done to this expression to make it particularly suitable for the computer. Due to the fixed point method of working, the majority of the calculation is performed with the integer and fractional representation of the terms in quantity to be summed. Only the evaluation of kt and the multiplicative factor for the whole summation has to be done in floating point representation.

The quantity L/t only takes values between the limits 0 and 1, and less than 1 h of computer time is sufficient to give a representative number of results within this range. From these results it is possible to obtain a continuous plot of L/t in terms of kt , which was the immediate requirement. This is shown in Fig.3.

Here once again, mathematically, the precise nature of the calculation to be done was known; only the enormity of the problem prevented its being carried out. Recourse to the computer reduced the size of the problem to reasonable proportions.

SOLUTION OF NON-LINEAR SIMULTANEOUS EQUATIONS

If some attempt is made to solve heat-transfer problems, including both radiative and convective heat transfer, the equations involved will include linear and fourth power terms in the temperatures involved. If these temperatures are to be evaluated, then it is very probable that the problem resolves itself into the solution of simultaneous non-linear equations. There is no hard and fast rule for the solution of such equations, and in general each group must be treated on its own merits. Whatever method is used for the treatment, it will almost certainly involve an iterative procedure. There will also be some element of a recognized method of solving simultaneous linear equations. Anyone who has solved, by hand, more than say five simultaneous linear equations will know that it is a tedious affair, and in fact programs have been written for many computers to solve them. If therefore, it is necessary to solve many sets of linear equations in order to solve one set of non-linear equations, there is even more justification for the use of a computer.

The most powerful method of solution tried by the author involved the determination and use of a crude approximation for each of the temperatures involved. These could be as much as 10% in error compared with their true values. Each non-linear term was then expressed as a linear expansion in a correction applied to this first approximation, for example, $(T)^4$ would be replaced by $(T^1)^4 + 4(T^1)^3e$, and linear terms were of course substituted for exactly, in terms of the known approximation (T^1) and the unknown correction 'e'. The terms in the equations could then be regrouped as a set of linear simultaneous equations in the unknown corrections. Solution of this set would yield a set of corrected first approximations from which a set of second corrections could be evaluated. It would be hoped that repetition of this process would yield a stable result, that is, the series of corrections would converge to zero.

This is perfectly satisfactory if the first approximation is a good one, but in general this is not possible. Some method has to be found of obtaining a good first approximation. It may be that the equations are only slightly non-linear. For example, all terms but one in

each equation may be of the same type, with the remaining term of much less numerical significance. Whatever value, within the range of possibility, is substituted for the temperature in these terms will not greatly affect the balance of the equation, and therefore good approximations to all the temperatures could be obtained by replacing these extra terms by their numerical values when the temperatures concerned are midway between the possible maximum and minimum limits. The resultant set of equations could then be considered to be linear, even in a non-linear function; for example, the equations could be linear in T^4 .

This method has yielded promising results for some of the equations which it was requested to solve. Most of the terms were the results of radiative heat transfer, with a minority of convective heat transfer terms, each of which was an order of magnitude smaller than the radiative terms.

Some method of analysis thus seems to have been found for this particular problem, but it still has to be transformed into a method directly acceptable to the computer. In this case it depends on the precise method to be used for the solution of the resultant simultaneous equations.

In the interest of overall time saving, rather than actual speed on the computer, it was decided to treat the whole problem as a matrix one. In this way the whole sequence of operations could be represented by a series of matrix equations. The underlying reason for this is the existence of the Pegasis Matrix Interpretive Scheme whereby matrix problems can be programmed for the computer in a simple and easy way. If anything outside the scope of the scheme is called for it is very simple to insert some extra orders to cater for this requirement. This in fact was found to be necessary when it was required to find the vector of T from the vector of T^4 .

CONCLUSIONS

The three studies described would not have been continued had not a computer been available. For the view factor evaluation some 12 months were necessary to derive the mathematical expressions in the correct form and to develop fully the resultant computer program. In the following 12 months a larger number of view factors were evaluated such that it is now possible to arrange the results in graphical form for the wide range of parameters considered. The results should be ready for publication later this year. Such a task by manual methods would be astronomical, and probably uneconomic.

While the furnace brick problem is much smaller, most of the foregoing remarks could well apply here. Time would again have been the major factor, and the problem might well have been shelved due to non-availability of human effort.

The question of non-linear equations is something of an enigma. It is realized that only a small corner of the field of types of equation has been tackled, and that the equations involved have been somewhat easy to treat. However, the work carried out has had a measure of success. A disturbing feature is the possible existence of more than one set of real roots within the range of possibility, e.g. for furnace temperatures in degrees absolute, this might be the range 0–2000°K. Different first estimates of the temperatures may lead to different results. No answer is offered at this stage to this difficulty.

ACKNOWLEDGMENTS

The author is indebted to Mr F. H. Saniter, O.B.E., Director of Research, The United Steel Companies Ltd, for permission to submit this paper, and to Professor D. B. Spalding for his advice and guidance on the view factor evaluation.

Stal in English

Number 8 (August 1961) of the cover-to-cover translation of the Russian journal *Stal'* has been published and no.9 (September) should appear later this month. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute. Brief details of no.9 are given below.

IRONMAKING

Radiometric investigation of blast-furnace tuyere zone

Discussion: open-hearth furnace or oxygen-blown converter? (Part 3)

STEELMAKING

High-speed carburization of steel in OH furnace

ROLLING AND TUBE PRODUCTION

Roll pass designs for forming ribbed plate

Mechanization of mandrel changing on automatic tube mills

METALWORKING AND HEAT TREATMENT

Selenium in cast and structural steels

Use of computers in continuous strip mills

P. Bouchaud and R. Feroldi

INTRODUCTION

CONSIDERABLE development is currently taking place in the use of office machines, especially with regard to machines for mechanizing office work, book-keeping, or commercial work, and into which data are generally introduced in a special form (punched cards, perforated tape, magnetic tape, magnetic recording, etc).

This development is due to two reasons which are not unconnected:

- (i) the requirements created by developments in mass production, if the latter is to be fully controlled
- (ii) the development of office machines which are becoming increasingly adapted to management business purposes.

In this development of equipment, an important advance has been the appearance of the 'computer', the features of which are: higher rate of data input and result output, due to the speed of punched card processing and also to the use of magnetic tape; high computing speed; the ease with which complex and advanced programs can be fed into the machines; and provision of a considerable data store, so that it is not only possible to record the working program, but also the data and tables necessary for its completion.

In short, the computer (as the central unit) and the magnetic tape (as information carrier) represent a considerable advance in speed and flexibility over previous equipment.

It is quite evident that the resulting mechanization can be applied to all kinds of problems, especially in the fields of administration, techniques (automation), and science.

For some time, many businesses have dealt with some of these problems by means of conventional machines, e.g. by tabulators and electronic calculators. This is the case, for example, with personnel administration; wage payment; management of stocks; costing; and statistics in any field.

It is, however, in production control that mechanization may be found to be most desirable, efficient, and promising. Therefore this particular field deserves our special attention. Production control is a term wide in scope, and it is difficult and probably unnecessary to define it exactly.

We shall confine our discussion to the principal

SYNOPSIS

With recent developments in the characteristics and in the use of office machines and computers, management now possess new means of solving problems resulting from mass production. In many fields, administrative, technical, and scientific, mechanization is found to be desirable. This paper deals particularly with mechanization in a production control department and deals with various processes which occur in a continuous strip mill for the completion of orders, e.g. specification of orders, starting of orders, follow-up of work in hand, and follow-up of orders. Advantages of mechanization are now evident: repetitive work is considerably reduced, flexibility is improved, selected solutions are better, and integration in different fields can be considered.

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administrative work required in continuous strip mills for the completion of an order from its entry to its shipment.

The written order received from the customer must first be analysed and translated into a production order, i.e. a document permitting the order to be executed at every stage. In short, the order must be specified. We shall refer to this task as 'specification of orders'.

The order is now in the 'order book,' and at a given moment it must be 'started', in other words, its execution must be initiated. This is the 'starting of orders'.

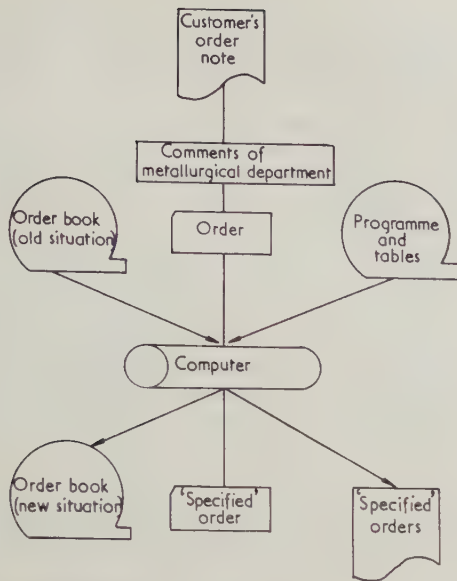
The manufacturing operations are put into effect by modifications of the metal, and the situation development must be known. We call this 'follow-up of work in hand'. The object of this process, however, is to fulfil the customer's order, of which the state of progress must be known. This is 'follow-up of orders'.

Finally, these various operations presuppose the determination of the values of certain parameters. For this purpose, operational research work is often employed; the computer makes this possible or convenient. A few examples will be mentioned.

We do not claim that our observations cover the entire range of production. These are perhaps not the most complex or important problems. They are, however, operations which must be carried out and their quality determines the running of the plant and, consequently, costs. They are operations of which we have experience, so that we are able to refer to them with confidence.

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1 Order specification

Finally, we would add that in what follows, the boundary between conventional business machines and computers is not always very definite. This does not imply any misrepresentation of the facts, since it is true that while the two types of machines differ in means and capacity, there is no difference in method.

SPECIFICATION OF ORDERS

The document received from the customer, or commercial department, defines the order by a limited number of parameters, which are in general: tonnage; dimensions; some mechanical properties and, sometimes, a few metallurgical characteristics; and delivery period.

It is usual, first of all, to pass this document to a metallurgical department which specifies certain factors relating to the quality to be obtained, and expertly directs the routing. After this, much further information is necessary to permit the work to be carried out. Without claiming to exhaust the list, the following may be mentioned:

- (i) the analysis of the routing, i.e. the indication of the various appliances through which the order will pass
- (ii) the tonnages at the various stages, taking into account the rejects and yields, which in turn depend on many factors
- (iii) the dimensions of the successive states from the ingot to the sheet metal
- (iv) the dates of the various operations, i.e. the time the metal takes to pass through each production unit
- (v) the technical essentials involved in the order: temperatures, elongation, surface characteristics, etc.
- (vi) secondary specifications, e.g. number of sheets and finishing circuits.

The manual execution of such a problem consists in consulting a certain number of tables or graphs. The machine work is almost the same and it is carried out by consulting tables in the computer. The procedure is outlined below (see Fig.1).

The customer's initial document is transferred to punched cards, which also include the information provided by the metallurgical department. The tables necessary for the work are numerous and voluminous; they must be recorded on magnetic tape.

The orders having been classified by identical series, the corresponding tables are introduced into the computer. For each order considered, the computer consults these tables and finds the information required. As output element for each order we have finally the complete specifications, these being partly in the form of documents in plain language, partly in the form of punched cards or in the form of magnetic tape intended for other uses.

Fundamentally, the work involved here is relatively simple, but its mechanization is amply justified.

There is a considerable saving in time. To specify daily 200 to 400 orders for example, plus daily 100 alterations to previous orders, one machine hour replaces about 20 office-staff hours. Almost all mistakes are eliminated. Manual processing, however, does involve errors because the work is repetitional and exacting. Furthermore, the rigidity of machine work necessarily excludes any interpretation, thus giving greater objectivity to the results.

Mechanization also achieves integration by carrying out, in one operation, tasks which are often done in different offices and at successive times. The result is better co-ordination and above all, complete mastery of specification rules.

Finally, it should be added that on the occasion of this work, other tasks are carried out or may be contemplated, such as: strict control of the standards of the products, that is to say, rejection of orders incompatible with the ordinary capabilities of the working appliances; supervision of the loads on production lines; and bringing up to date the order book which is, in the main, formed by a magnetic tape used for other jobs.

STARTING OF ORDERS

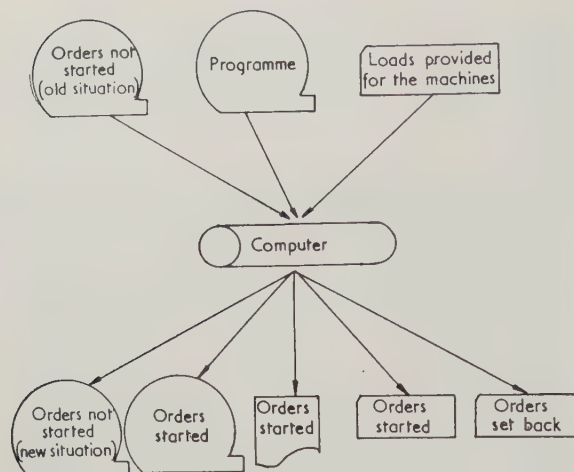
The recorded orders form the order book. Some of them are received well in advance, others on the contrary arrive at the last moment and are urgent orders as soon as they arrive. They must, in any case, be started; that is to say, at a given moment their execution must be initiated.

This problem is dealt with periodically; once a week appears to be a convenient frequency and one which is often adopted.

In fact it consists of a weekly selection of 1500 orders from an order book of 5000 orders.

This represents a weekly selected tonnage of 45000 tons.

This amounts to selecting in the order book the order which it is expedient to start at a given moment. It is evident that the time factor is predominant and this is the problem. An order must be started in good time so that the delivery period stipulated by the customer will not be exceeded. On the other hand, the order should not be ready too soon, because this will encumber the stores for orders awaiting despatch. In arithmetical terms the starting data is the stipulated delivery period less the production time. Fortunately, in practice, the actual position is more flexible.



2 Starting of orders

First of all, the delivery period includes a tolerance, mostly provided by the customer or even self-imposed, for example by accepting a certain delay in store before despatch.

Furthermore, the manufacturing period may vary according to certain alternatives. There may be several possible routings of different duration. Some means of speeding up the work is also possible.

These various degrees of freedom make it possible, in regard to the delivery period, to allocate priority to certain essentials. A thorough study of the problem will indicate which priorities are expedient for the particular problem. Thus, in a period of heavy commitment it would be wise to ascertain the maximum load on the different production lines.

The problem therefore becomes one of selecting the orders so that they will be completed in time, so that small tonnages may be combined, and so as to take into account the loads best suited for the various production lines (and above all to avoid fluctuations).

These general considerations need amplification.

(i) The problem can be solved, as we have seen, because there are certain degrees of freedom. This freedom must, however, be sufficient. Should the order book be in a state of confusion, starting would be unsatisfactory, that is to say, the production units would not be sufficiently loaded, while many orders would be delayed. There is, therefore, a preliminary stage in making up the order book, for which medium-term and long-term forecasting are employed, and within the framework of which the orders are taken. This is checked when the orders are booked.

(ii) The starting of an order affects the load on the plants for several weeks, because production itself is spread over several weeks. The data of the problem, therefore, include the load on the various machines during the weeks to come.

(iii) The term 'load on a production unit' involves breaking down the tonnages according to various criteria, or priorities. For example, the capacity of a steel plant is analysed according to steel qualities and types of ingot. The capacities of a rolling mill are related to the various sizes dealt with in one set-up of rolls. When one starts to list these priorities in a plant one finds that the number mounts up. We have now to take into account more than 50 of them. Furthermore,

these capacities are brought up to date at each computer operation (let us say every week) to take fresh events into account (plant maintenance, holidays, etc.).

(iv) Despite the precautions taken, and despite the various possible alternatives, some orders are set back and from then onward are referred to as delayed. Actually, they are not very numerous and may be treated as exceptions.

Ultimately, the starting operation consists of (see Fig.2): (a) introducing into the machine the loads provided per plant for the weeks to come (b) examining in succession the orders booked, so as to start them if their delivery period demands it, provided that this is compatible with the loads on the plants, and (c) indicating the orders which cannot be put in hand and which would, therefore, be outside the delivery period.

Actually, this description of the procedure is a simplified picture of the work. The problem is more complex and more varied. For instance, we have implicitly assumed that the start of an order necessarily occurred at the first stage, i.e. on the steel plant. However, this is not always the case. On the one hand, excess metal may occur at any point of the chain, owing either to some particularly successful operation or, on the contrary, to an unsuccessful operation. On the other hand, for cutting short the delivery periods or for other reasons, it may be considered desirable to use judiciously replenished intermediate stocks.

Finally, we would add that this problem is one of the most important which a production control department has to solve. Consequently, its solutions will be peculiar to each firm. Different solutions depending on the general policy of the concern, its degree of mechanization, and its general attitude, will be adopted.

We have endeavoured to show that the quantity, the complexity, and the consequences of this work are such that manual handling can only be an approximation. It is the prototype of tasks for which powerful means, such as computers, are necessary to cope with the various parameters and to arrive at the required result in an acceptable period.

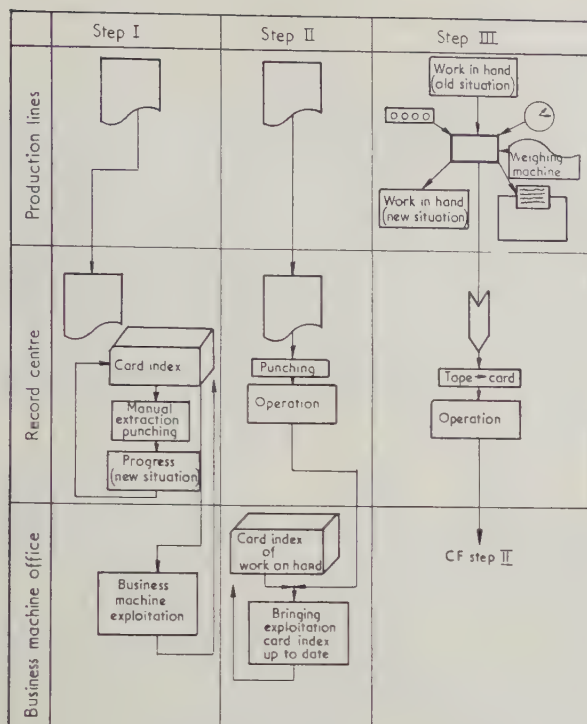
FOLLOW-UP OF WORK IN HAND

The fulfilment of the order is achieved by production operations, that is to say, movements of the metal. In the course of the cycle, the units of metal are modified or altered, as the ingot becomes a slab, the slab gives rise to a coil, and the coil is cut into sheets.

We have no need to emphasize the fact that it is essential to follow this process. Nor shall we seek to prove that this work may be mechanized, since numerous firms have already introduced the punched card in this field.

The underlying basis of this problem is a card index, in which each unit of metal is represented by a card brought up to date at each production operation. On the face of it, this work appears to be easy, yet the limited objective of keeping this card index is not easily achieved. What then are the obstacles to be overcome?

In hot mill operations, at the slab or coil stage, the speed of production is a main difficulty. In cold mill



3 Follow-up of work in hand

operations, there is more complexity, i.e. more numerous and more varied treatments; sometimes indeed the metal passes twice through the same machine.

More serious still are the difficulties arising from changes which modify the identity of the unit of metal, whether it concerns successive stages (ingots, slabs, coils, packs), or welding operations (pickling, for example), or sub-division (cold-rolling coils in particular when they break or when they are cut). These changes must be followed without losing the real identity of the metal. Translated into punched cards, this development results in the production of new cards and the elimination of out-of-date cards.

Finally, the transmission of information between the production lines and the administrative centres sets serious problems in regard to achieving the precision, reliability, and speed required in this activity. On this particular point, mechanization leads to a study of more or less complicated remote-transmission devices. Numerous studies are in progress either at steelworks or at equipment manufacturers. No doubt these projects will produce practical results in the years to come.

By simplification and schematizing, this problem can be seen to have three solutions, which are also three stages. They are shown in Fig.3.

In solution I, a punched-card index is dealt with manually. The manual part of the work is complemented by a check on the information sent by the production lines. This solution, which is cumbersome, is inevitable as long as the quality of the information received is inadequate.

In solution II, it is assumed that the information received may be punched directly and thus give rise to an 'operation' card. Keeping the index up to date is then done mechanically, by means of office machines.

It appears desirable, however, to produce the 'operation' card automatically. This is the basis of solution III. The unit of metal is accompanied by a card expressing its former situation. In the course of the work, the production operator introduces into a reader the 'previous situation' card, which he completes with the new data either by manual addition or by automatic recording (weighing machines, for example). There is thus obtained a 'new situation' card accompanying the element of metal, and an 'operation' card for bringing the card index up to date.

In short, the developments made in this field have the object of making the transmission of information and the bringing up to date of the card index as automatic as possible.

In the diagram of Fig.3, the term 'business machine exploitation' has been given to the operations carried out from the card index of the work in hand. They are numerous and affect various sections: production, book-keeping, production bonuses, etc. They appear in the form of progress reports, steel stock lists, corrected production returns, etc.

In regard to production, after *steel in hand* cards and *order* cards have been grouped manually, scheduling of the production units can be effected by means of conventional office machines.

In short, the problem of following-up work in hand, however simple it may be in principle, involves numerous practical difficulties; with regard to the exploitation of the card index, it assumes multiple forms, among which the scheduling of the production units is in itself an important and delicate problem.

We feel that the limits of conventional office machines have been reached in this field, owing to the volume of information, the working rhythm involved, and the nature of the exploitation which one may be called upon to perform. In this case the punched card is too clumsy and too slow a device. There exists undoubtedly a sphere of application for new means, let us say for computers, computers considered at first as information collectors and then being gradually used in preparing the scheduling of the production units. This will become evident as time goes on.

FOLLOW-UP OF ORDERS

A knowledge of the state of progress of the orders is necessary all along the production line. The order which is started goes through different stages of successive scheduling on the various appliances. It is therefore necessary to know its state of progress. This is important for the final operations: the preparation and despatch of the material when it has been completely processed. It is even more important when the material is incompletely processed: it must be handled with a full knowledge of the situation. Furthermore, it is necessary to be able to inform the customers or the commercial department; this is an essential part of the service owed to the customers.

In fact, the work of following up the orders is always done with the greatest care in any plant. However, with developments in production, manual processes have been found to be very unwieldy, so that recourse has been made to office machine methods for facilitating this task.

In the problems discussed above, the concept of the order was one of the basic parameters of the work.

This is explicit, in all that concerns the order book, which, as we have seen, may be carried on magnetic tape. It is implied in the follow-up of work in hand, because a unit of metal is always assigned to an order more or less directly and definitely.

There are therefore two fields in which order follow-up is relevant. In the works, within the framework of the problem of the work in hand, the order parameter is present in the card index we have mentioned. A special operation therefore will show, in regard to a given order, the position of the different units of metal assigned to it. This may be translated into tonnages before pickling, tonnages after rolling, tonnages ready for despatch, etc. This information will make it possible to schedule, i.e. to start and direct the successive manufacturing operations upstream and downstream.

This information, however, is also received by the central group of the production control department which, in more synthetic form, brings up to date the magnetic tape including a 'recording' by order. From this tape, brought up to date, are drawn up the returns, to which are added exception reports relating to anomalies.

The importance of such work is obvious, and therefore we shall not dwell any further on this subject. We wish, however, to mention the conception of 'integrated management' which is common in this field. Any event, in particular, a manufacturing operation, has numerous repercussions in various fields. Owing to mechanization, the various pieces of work are carried out with the same data which have only been recorded once on a punched card. This eliminates the numerous duplicates which manual processes involve, and consequently the resulting mistakes. With magnetic tape, the process is still better, since manual intervention is reduced still further.

OPERATIONAL RESEARCH PROBLEMS

Although it is not the subject of this paper the use of the computer for operational research problems in the field of production deserves some mention.

The examples will be taken from the province of order starting. We have seen that one of the elements of this problem is the load to be provided for the production lines. This load may be determined from statistics collected in the past. It may, however, also be the subject of special work, for example on the occasion of modification or extension of plants. Furthermore, for fixing long-term programmes, it may be necessary to study the extension of the means for obtaining a given level of production or for removing bottle-necks in production. Thus, we have been obliged, for instance, to ascertain the number of soaking pits required for ensuring a given level of slab production.

Another example may be produced in connexion with the diminution of intermediate stock. For some orders, a start is made, not from the steel plant, but from an intermediate stock of metal. Thus, for instance, in the production of tinplate in certain sizes coils stocked before pickling are used. A certain amount of excess side trimming is accepted, provided the corresponding cost is less than certain values. The problem consists in calculating the amount of these stocks in the different sizes of coils, according to certain hypotheses of the order books.

CONCLUSION

We will conclude with a few observations of a general nature.

First, we must stress the incomplete and temporary character of the processes outlined. We are dealing with a subject which, although not new, is currently undergoing profound modification. Probably the appearance of computers, and their utilization for administrative purposes have caused this.

In addition, the technique of these machines is rapidly being altered; their adaptation to the problems of businesses is being improved and this tends to enlarge the problem. Furthermore, the operators themselves are well aware of the provisional nature of their methods. Operational programmes have to be revised or changed frequently. Everything is in a state of flux.

This feeling of instability, however, is accompanied by a certainty of improvement and evidence of progress. The difficulties, it is true, are many and mistakes and uncertainties are common. But favourable results are being obtained.

First of all, repetitional work without human interest, if not eliminated, is at least considerably reduced. The automatic control of production machines has made manufacturing work less arduous.

Also the results obtained are manifestly better. Mass production with its rhythm and its too numerous parameters involves us in complex and confused situations. The modern processes we have discussed are sweeping away the feeling of frustration which is sometimes experienced. It is also found that the problem is handled better because the actual state of affairs is analysed better.

Moreover, management may know at any time which rules are applied all the way down the production lines; which rules are difficult to follow or not easily compatible with others; and also which orders cannot comply with the rules.

This may be called 'optimization' and may be applied simultaneously in fields as varied as: production costs (for the benefit of the concern); accuracy in delivery (for the benefit of the customer); and use of employment or of production capacity at their best (for the benefit of the plant itself).

We must not, however, neglect the psychological problems which these processes impose. An order recorded on magnetic tape cannot be consulted as can a document in plain language. In many cases, the visual check on the operations disappears. The results emerge, information regarding anomalies is received, but the total process goes unrecorded.

Finally, let us say that the mechanical solution of problems means that they must be dealt with thoroughly, that is to say, one must examine and analyse them fully. Experience and expert knowledge of office-machine techniques are also essential.

Among the qualities necessary for success in this work, confidence in office machinery is needed. Also, to some extent, faith and even enthusiasm; qualities of youth.

There must be constancy of effort, accuracy in reasoning and mastering of the problems; characteristics of maturity.

These conflicting qualities will not often be found in any one man. This is a reason for believing that success in this field can only be achieved by teamwork.

The mechanism of carbide solution during the austenitization of high-speed steels

Z. Bojarski, D.T.Sc., M.A., Ch.E.

INTRODUCTION

FROM PREVIOUS WORK¹ on the phase constitutions and chemical compositions of carbides in high-speed steels, it may be supposed that the chemical composition of the fundamental M_6C -carbide changes during austenitization of the steel. The behaviour of this carbide has been studied by Gulaev,² Arkharov *et al.*,³ Goldschmidt,⁴ McHargue *et al.*,⁵ and others⁶; the point has been raised also in discussion of the work¹ by Hoyle.⁷

Opinions on the mechanism of M_6C solution during austenitization differ; some workers suggest that the carbides do not change, and others suppose that they do. Therefore it was decided to investigate the matter in more detail. There was a possibility that the known phenomenon of carbides assuming a polygonal form during high-temperature austenitization, might be connected with changes in their chemical composition.

MATERIALS AND METHODS

For the investigations, 18-4-1 and 9-4-2 types high-speed steel were used, from the same source as steels used in previous work¹; the heat treatment of the samples was also identical. The extraction of the carbides from the steel was carried out using 5% HCl (aqueous solution) as an electrolyte, and a current density of 0.01 A/cm². The residue cleaned from the electrolyte was used as the material for X-ray examination.

The austenitizing times of 1, 5, 10, and 20 min were too short for attaining a state of equilibrium between the matrix and the carbides. Nevertheless the metastable state attained in the system was of interest because of similarity in heat treatment of the steel with the conditions occurring in industrial practice.

X-ray examination in the form of a precision determination of the lattice parameters, was chosen as the basic method of investigating the carbide structure at various austenitizing temperatures, because evidence of variations in M_6C spacings according to the austenitizing temperature, would make it possible to detect changes in their character.

Changes in chemical composition may occur by diffusion of individual elements from the carbide to the matrix, or *vice versa*. Therefore the chemical com-

SYNOPSIS

Precision measurements have been made of the lattice constants of M_6C -carbide occurring in quenched and annealed high-speed steels of 18-4-1 and 9-4-2 types.

Austenitization has been carried out in the 900-1300°C temperature range, with soaking times of 1-120 min.

It was found that under these heat-treatment conditions the M_6C -carbide is stable, but its lattice parameter changes owing to coagulation and diffusion processes between matrix and carbides. A rapid increase in the lattice parameters of the carbide is observed during which it assumes a polygonal form for austenitizing temperatures from 1250°C.

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position of the individual carbide crystallites in the metastable state, is liable to show unhomogeneity, so that the lattice parameters within a single crystallite should also vary. To study the chemical unhomogeneity of an individual carbide crystallite, and the diffusion processes involved, a method of precision measurement of the lattice constants was applied using radiation of different wavelengths. The feasibility of this method was shown by A. Kochanovska.⁸

To obtain data on structural and quantitative changes in the carbides, a microscope study was carried out along with the X-ray examination. Accurate data of the carbide contents have been given previously.¹

RESULTS

With a rise in austenitizing temperature the number of carbide grains distinctly diminishes. In the 18-4-1 steel their size and shape also change. With a temperature of 1250°C the change in shape is clearly visible. On the polished samples the carbides assume a polygonal form, mostly square or rectangular (Fig.1).

The samples of austenitized 9-4-2 steel do not show any visible changes in shape and grain size of the carbides, up to a temperature of 1260°C; they remain roughly spherical and are distributed within the grains as well as the boundaries. Compared with the samples of 18-4-1 steel the number of undissolved carbide grains is insignificant.

X-ray patterns were obtained using Co and Cr K α radiations. It has been calculated that the penetration

TABLE I Characteristic data of M_6C -carbide reflections used in precision lattice constant measurements

No.	h k l	$h^2+k^2+l^2$	Range of Bragg angles, degrees	
			$K\alpha_1$ Co $\lambda_1=1.78529\text{kX}$ $K\alpha_2$ Co $\lambda_2=1.78919\text{kX}$	$K\alpha_1$ Cr $\lambda_1=2.28503\text{kX}$ $K\alpha_2$ Cr $\lambda_2=2.28821\text{kX}$
1	1060 136	866	70-71	...
2	1200 144	884	76-77	...
3	1151 147	777	78-79	...
4	911 83	...	...	70-71
5	664 88	...	...	76-77

depth* for Cr $K\alpha$ radiation was about $1.5\text{ }\mu\text{m}$, and for Co $K\alpha$ radiation about $2.7\text{ }\mu\text{m}$. In this calculation extinction effects were disregarded.

Table I shows data of the reflections used for the measurement of lattice parameters.

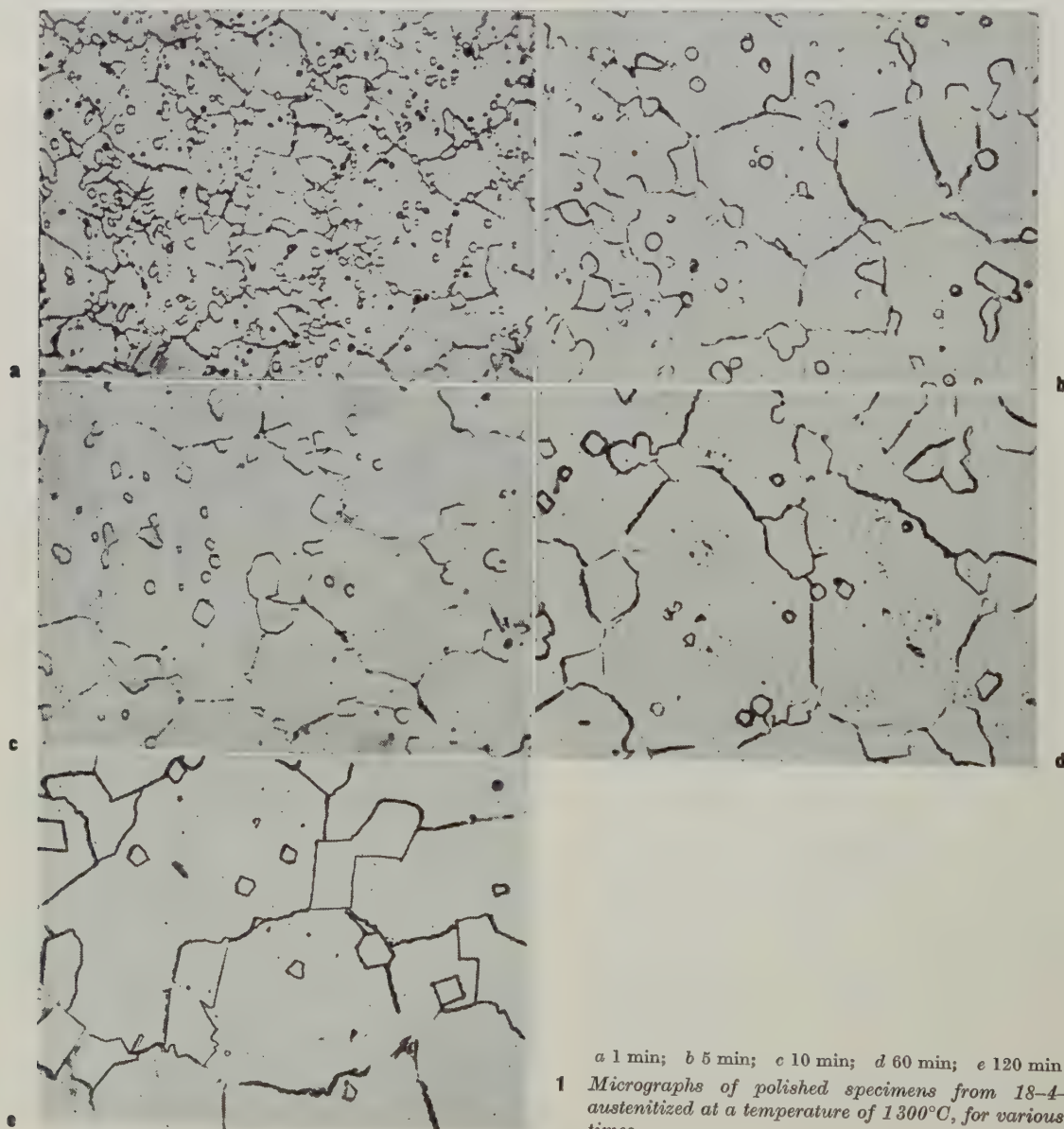
* 'Penetration depth' is taken as the thickness of material effectively contributing to the observed diffraction pattern.

X-ray patterns were obtained by the Straumanis technique, using powder cameras of 114.6 mm dia., and specimens of 0.3 mm dia., made by powdering the carbides and mounting on glass rods.

To compare the values of the parameters obtained by using different radiations, graphical extrapolation of the spacing values to $\theta=90^\circ$ was used as a function of $1/2\cos\theta\cot\theta+\theta^{-1}\cos^2\theta$ (Nelson and Riley's method).⁹ This eliminates the systematic errors inherent in the precision determination of lattice parameters, except for correction for X-ray refraction, which was calculated according to Peiser *et al.*¹⁰ The general accuracy of measurement was $\pm 0.0002\text{ kX}$.

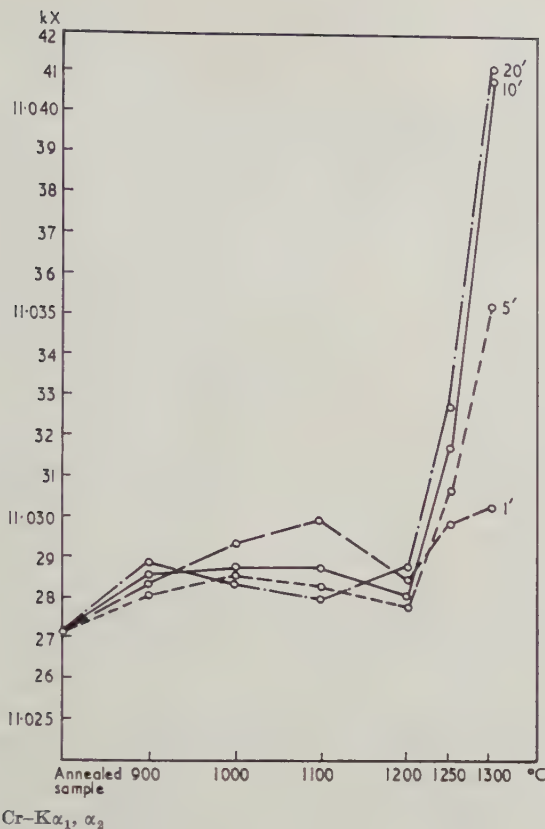
Figures 2-5 show the M_6C lattice constant values plotted against austenitization temperature and time.

Microscopic and chemical examinations¹ indicate that during austenitization of high-speed steel two phenomena occurred to which the M_6C -carbides are susceptible. The first consists in the solution of the carbides in the matrix, and has a decisive influence on its alloy content, control of which is the main object



a 1 min; b 5 min; c 10 min; d 60 min; e 120 min

1 Micrographs of polished specimens from 18-4-1 steel, austenitized at a temperature of 1300°C , for various soaking times



2 M_6C lattice parameter of 18-4-1 steel v. temperature and austenitizing time

of steel austenitization. The second phenomenon manifests itself in the growth of the carbides, and in their assumption of a polygonal shape; it mostly takes place at high temperatures and for longer austenitizing times.

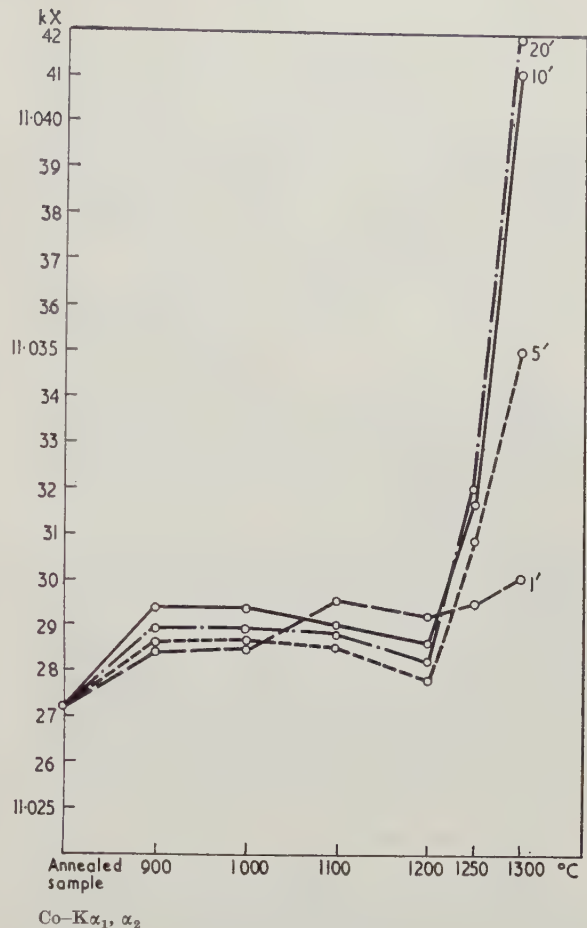
X-ray examinations indicate that the M_6C -carbide structure does not change during austenitizing times up to 20 min in the temperature range 900–1300°C.¹ To ascertain the carbide behaviour for longer austenitizing times, the 18-4-1 steel samples were soaked at 1300°C for 1 and 2 h.

X-ray patterns of residues from samples thus treated indicate reflections characteristic of the M_6C -carbide. Consequently the M_6C -carbide is stable and untransformable under normal austenitizing conditions.

Nevertheless Figs.2–5 show quite clearly that the lattice parameters of the M_6C -carbide change independently of the steel austenitizing conditions. The change is connected with alterations in the chemical composition of the carbide. From the atomic sizes, and the carbide structure, it is clear that the cause of the increase of M_6C -carbide lattice parameter should be attributed to its enrichment in W or V atoms; but a decrease may result from the vacancies in the lattice

TABLE II Chemical composition of M_6C -carbides from annealed and austenitized 18-4-1 steel

Heat treatment	W, %	Cr, %	V, %	Fe, %	C, %
Annealed 5 h at 800°C	63.42	4.99	4.04	24.83	2.46
Annealed 20 min at 1200°C	65.07	3.67	2.98	25.01	2.28
Annealed 60 min at 1300°C	66.67	3.50	2.70	24.98	2.27
Annealed 120 min at 1300°C	66.20	3.49	2.85	24.52	2.18



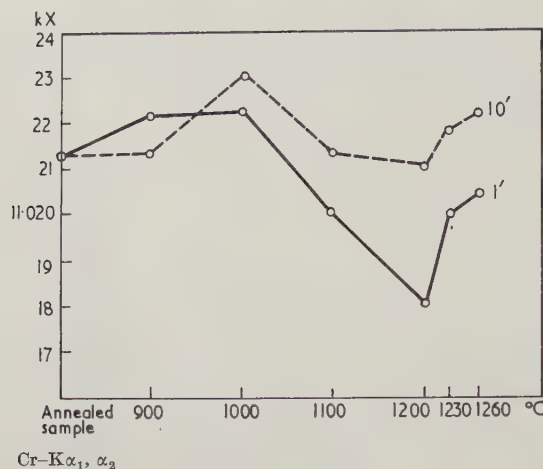
3 M_6C lattice parameter of 18-4-1 steel v. temperature and austenitizing time

produced by diffusion of atoms especially of Cr and Fe, to the matrix. The effect of carbon atoms on carbide lattice parameter, and the significance of their lattice positions need further consideration.

Measurement of lattice constants (Figs.2 and 4) showed that the M_6C -carbide unit cells are distinctly larger in 18-4-1 than in 9-4-2 steel. Therefore the chemical composition of carbides in these steels also differs. Chemical analysis ought to confirm this directly, but owing to the presence of MC -carbide in the residue there are difficulties in a selective separation of M_6C -carbide from the 9-4-2 steel.

The results of the previous work¹ showed that, besides the M_6C -carbide, the 18-4-1 steel also contains the $M_{23}C_6$ -carbide; it can be separated by use of the Popova method.¹¹ X-ray examinations did not show the presence of MC -carbide in the residue, but it could occur in small amounts below 2%. Separations of the elementary carbon have been made by Gutman's method.¹² (This method does not ensure a quantitative separation.) Therefore a selective separation of M_6C -carbide from the 18-4-1 steel residue, and an analysis without risk of major errors in the results became possible. Table II contains the results of chemical analysis of the carbides from 18-4-1 steel after various heat treatments.

In spite of the similar course of the M_6C -carbide parameter changes, dependent on austenitizing



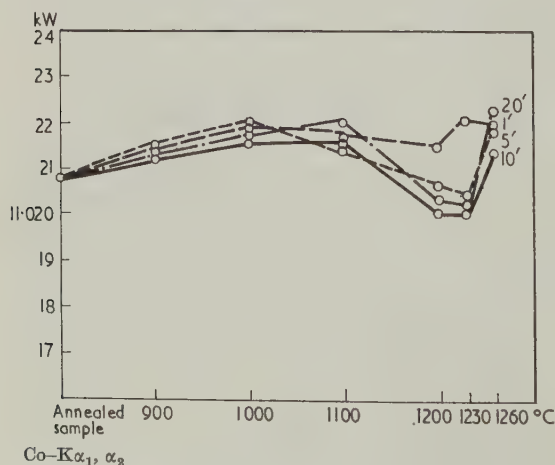
4 M_6C lattice parameter of 9-4-2 steel v. temperature and austenitizing time

temperature and time for the 18-4-1 and 9-4-2 steels, quantitative differences occur (Figs.2-5).

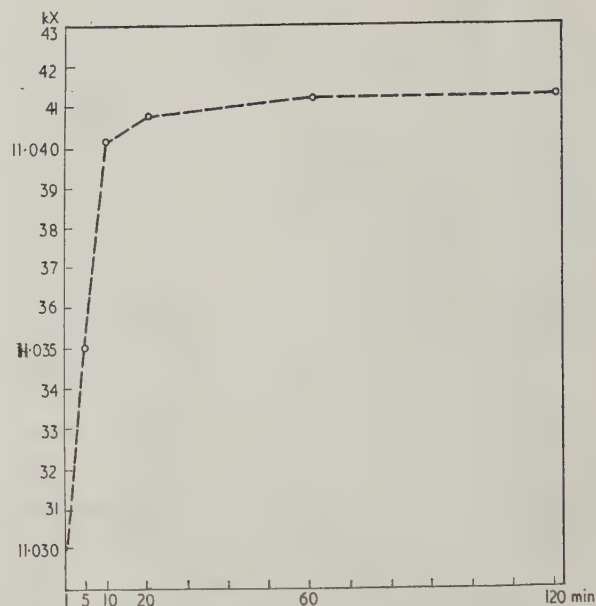
As to the annealed state produced by austenitizing at 900°C, an increase of the parameters may be observed. There is a possibility that this effect is caused by an unhomogeneity in chemical composition of the crystallites. Also the tungsten-poorer outer layers dissolve first. The parameters measured with Co radiation, penetrating deeper into the crystallites, are larger in that temperature range than the parameters measured with Cr radiation.

The cause for the observed decrease of carbide parameters, which begins, depending on steel austenitizing time, at a temperature of from 1000° to 1100°C and attains its minimum at 1200°C, should be sought in the diffusion processes involving the abandonment of the carbide lattice by the weaker carbide-forming atoms contained in it (e.g. Cr).

The changes of carbide lattice parameters, occurring at austenitization temperatures of 900-1200°C are, in comparison with the strong increase in the temperature range 1200-1300°C, much smaller (especially in 18-4-1 steel). The increase in these parameters is likely to be due to the enrichment of the carbide by tungsten or vanadium.



5 M_6C lattice parameter of 9-4-2 steel v. temperature and austenitizing time



6 M_6C lattice parameter of 18-4-1 steel austenitized at temperature 1300°C v. austenitizing time

The rapid parameter increase indicates that there is a greater probability of carbide enrichment by tungsten than vanadium.

The growth of carbide grains (Fig.1) occurs in parallel with the rapid increase in carbide lattice parameters. The lattice constant measurement concerns the outer layers deposited on the grains during coagulation when the matrix already contains about 8%W; consequently the outer layers are tungsten-richer. The cause therefore of the rapid increase of carbide lattice parameters is the deposition of new tungsten-richer layers. From a certain soaking time at austenitizing temperatures onwards the carbide parameters change only slightly (Fig.6).

The formation of polygonal grains may be due to their directional growth, related to the lattice symmetry, as suggested by McHargue *et al.*⁵

The use of two different radiations ($K\alpha_1, \alpha_2$ Cr and $K\alpha_1, \alpha_2$ Co) for measuring the parameters of the same carbide, permits a confirmation of the unhomogeneities within the single crystallite. These unhomogeneities, occurring in carbides separated from the steels which had short times and lower temperature of austenitization, are the reason for the differences in the parameter, as measured by using the two kinds of radiation, because under these conditions the diffusion processes between the matrix and the carbides comprise mostly the layers nearest the surface. Therefore the parameter values obtained by Cr radiation differ from those obtained by Co radiation, which has nearly twice the penetration. For the same reason the X-ray patterns obtained with Cr radiation, comprising only the surface layers of the crystallites, show much greater sensitivity to the changes occurring in these layers. In comparison with the data obtained by Co radiation, this expresses itself in the magnitude of the effects, i.e. in a decrease or an increase of the lattice spacing.

The parameters calculated from the X-ray patterns based on Cr and Co radiation become equal, if time and temperature of austenitization are long and high enough respectively. This indicates a homogeneity of

the crystallites up to the penetrating depth of Co radiation.

The distinct changes of the M_6C lattice parameters during steel austenitization, which are connected with changes in their chemical composition, confirm the observations of Arkharov *et al.*,³ yet they seem to contradict the results given by Goldschmidt⁴ and McHargue,⁵ who had not observed such a change. An explanation may be the different heat treatments of steels used by the above authors.

McHargue⁵ compared the lattice parameters of carbides separated from steels of relatively long-time and high-temperature austenitization.

The present investigations showed that (Fig. 6), in agreement with McHargue's statement, the M_6C parameter becomes stabilized during long times and at relatively high austenitization temperatures; and afterwards only insignificant changes are liable to occur. Nevertheless there is a possibility that McHargue compared parameters of carbides in which the composition had already been stabilized.

Goldschmidt compared the parameters of M_6C separated from an annealed steel, with one quenched from 1300°C, but gave no details of the austenitizing time of the samples. It is possible therefore that the austenitizing time was too short for the development of the diffusion processes, and consequently for the changes of carbide lattice parameter. Apart from the absence of a statement of the changes in carbide lattice values, Goldschmidt does not deny entirely the possibility of carbide composition changes during heat treatment.

On the basis of investigations carried out on the mechanism of M_6C -carbide solution, it is possible to distinguish two stages.

The first includes the range of austenitizing temperatures up to 1200°C, and is characterized by comparatively slight changes of the lattice constant and of grain size. In that range the diffusion processes between the matrix and the carbides, and the dissolution of the tungsten-poorer outer carbide layers, play a fundamental part.

The second stage includes temperatures over 1200°C, and is characterized by a solution of an important amount of M_6C , a rapid increase of the lattice constant, and of the grain size of the undissolved carbide. At the same time the carbides assume a polygonal shape. During that stage a coagulation of carbide grains takes place, the core consisting of more stable, undissolved carbides. The new layers forming around them are tungsten richer.

CONCLUSIONS

1. The M_6C -carbide is relatively stable and for the usual steel austenitizing conditions does not change into another crystalline form.

2. The chemical composition of M_6C varies with steel composition, e.g. M_6C -carbide of 18-4-1 steel is tungsten richer than that of 9-4-2 steel.

3. The parameters of the M_6C -carbide lattice change during steel austenitization owing to the diffusion processes between the matrix and the carbides and owing to coagulation processes. Qualitatively the character of these changes is similar for carbides of 18-4-1 and 9-4-2 steels. The occurrence of quantitative differences is due to differences in chemical composition of these carbides, diffusion conditions, because of lower austenitizing temperatures, and a smaller amount of undissolved carbides.

4. At high-speed steel austenitizing temperatures the carbide grain growth is a result of coagulation. Moreover the new layers growing are of different chemical composition than the core; this is confirmed by a significant increase in size of the lattice.

5. The formation of polygonal carbides is connected with the tendency of the grains to attain a minimum surface energy, not by a minimal surface, but through development of planes of lowest surface energy in agreement with McHargue *et al.*

6. The unhomogeneities proved to exist within an individual M_6C crystallite for comparatively low temperatures and short times of austenitization are connected with the diffusion effect dominant under those conditions, most of all in the surface layers.

ACKNOWLEDGMENT

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Fuel additions and blast modifications in the blast-furnace

H. B. Bell and J. Taylor

INTRODUCTION

THE POSSIBILITIES associated with replacement of a part of the metallurgical coke by alternative fuels and modifications of the combustion air in the iron blast-furnace are attracting increasing attention. A theoretical analysis of the problems can be based on two considerations. In the first place the effect of these variables on the thermal economy of the furnace can be calculated from the overall thermal balance. In the second place regard must be paid to the thermal potential (temperature) of the reducing gases. When attention was first directed to this latter aspect of blast-furnace theory by Johnston¹ the emphasis was on the need to generate heat in the hearth at a temperature sufficient to raise the products, slag and metal, to the required operating temperature. Under modern conditions this limitation hardly arises but the vertical temperature distribution in the stack is affected by the temperature of the ascending reducing gas and this is a most important operating factor. In particular a steep temperature gradient in the lower part of the furnace is associated with sticky and erratic operation. This has in the past proved a limitation to the use of high blast temperatures. Practical experience showed that beyond a certain point, which varied with conditions, the theoretical advantages of supplying additional heat as sensible heat of the blast was more than offset by the poorer reduction efficiency resulting from erratic stock descent.

In the present state of knowledge it does not appear possible to estimate the vertical temperature distribution with any degree of precision. Even the first stage in such a calculation, the gas-solid temperature differences, requires information on the progress of reactions within the furnace which is not available. If assumptions are made as to the progress of the reactions, gas-solid temperature differences can be calculated² but it must be appreciated that the absolute value of the results is of very doubtful significance. The comparative values of calculations designed to illustrate the effect of different variables are much more significant and it is considered that they are a very useful qualitative guide to the effect of such variables as blast temperature, burden composition, etc. In the present context we are concerned with one set of variables, increase in blast temperature and oxygen

SYNOPSIS

The effect of oil, coal, and coke-oven gas injection on the fuel requirements of the blast-furnace has been calculated. The basis of comparison is in the first place unchanged gaseous reduction efficiency. Factors are given for the coke equivalents of these fuels together with factors for changes in blast temperature, moisture, and thermal requirements.

Compensation for fuel or moisture additions by increases in blast temperature or oxygen content have been examined through the gas-solid temperature differences in the stack. It is found that tuyere combustion temperature is a sufficient guide and graphs are given showing compensating additions necessary to maintain the tuyere combustion temperature constant.

Although the comparisons have been based on constant reduction efficiency the question of the improvements in reduction efficiency that might be achieved has been examined both theoretically and by analysis of available data on injection trials.

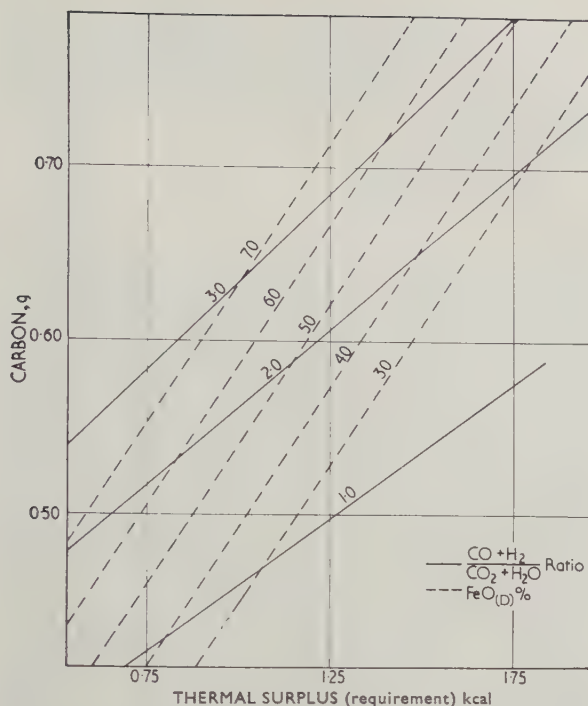
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enrichment, which increases gas-solid temperature differences in the lower part of the furnace, and another set of variables, fuel injection and steam additions to the blast, which decreases these differences. Calculations can be made to show what combinations of steam or fuel on the one hand and increased blast heat or oxygen enrichment on the other will maintain gas-solid temperature differences substantially unchanged. If therefore we take tried and proved operating conditions for any given practice as a norm, and at the moment only by practical experience can a norm be established, the combinations of fuel or steam and heat or oxygen necessary to maintain that norm can be calculated.

The data for these calculations must be obtained through the thermal balance and it would be exceedingly laborious if it were necessary to arrive at the combinations by a process of trial and error. Fortunately, as shown later, the combustion temperature at the tuyeres is a very good guide. If the combinations necessary to maintain this constant are calculated then in most cases the gas-solid temperature differences up the stack are also maintained substantially constant. In the subsequent discussion constant tuyere combustion temperature is taken as the criterion of constant operating conditions.

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Basis 1g Fe; blast temp. 800°C; top gas temp. 200°C

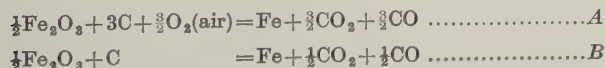
1 Carbon rate *v.* thermal requirement for coke fuel

THE THERMAL BALANCE

Effects of thermal requirements, blast temperature, and degree of reduction

For the thermal balance calculations we have followed the method used in a previous paper.³ The balance is made in two parts. On the one side is the thermal change associated with the combustion of the fuel and the reduction of iron oxide. On the other side is the heat required for sensible heat of metal and slag, reduction of metalloids, cooling losses, etc. There must be a thermal surplus from the first part equal to the thermal requirements of the second. The effects of the variables under consideration only enter the first part.

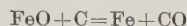
If we consider first normal practice, there are two limiting cases for the reduction of iron oxide with carbon. In case *A* all the carbon is burnt to CO at the tuyeres and reduction of iron oxide is entirely by CO, i.e. reduction is 100% indirect. In case *B* all the carbon reacts with iron oxide to give CO + CO₂, i.e. reduction is a combination of direct and indirect. If Fe₂O₃ is taken as the commonest form of iron oxide then for a CO/CO₂ ratio of 1.0 reactions *A* and *B* can be represented



Similar equations can be constructed for any chosen CO/CO₂ ratio and the heats of reaction obtained from standard thermochemical data and the heat of combustion of coke carbon (see Appendix). Reaction *B* is endothermic and it can readily be shown that even for poor CO/CO₂ ratios the heat developed by reaction *A* is far in excess of the thermal requirements of the remainder of the process. Therefore, in the blast-furnace, iron oxide reduction is always by a mixture of

reactions *A* and *B*. The thermal surplus resulting from the reduction of Fe₂O₃ and combustion of coke can be calculated from the reaction heats of *A* and *B*, and the sensible heats of air and top gas. In the subsequent calculations air temperature has been considered as a variable but since top gas temperature is an uncontrolled variable a temperature of 200°C has been assumed for all calculations. An example of this calculation is shown in Table 1 of the Appendix.

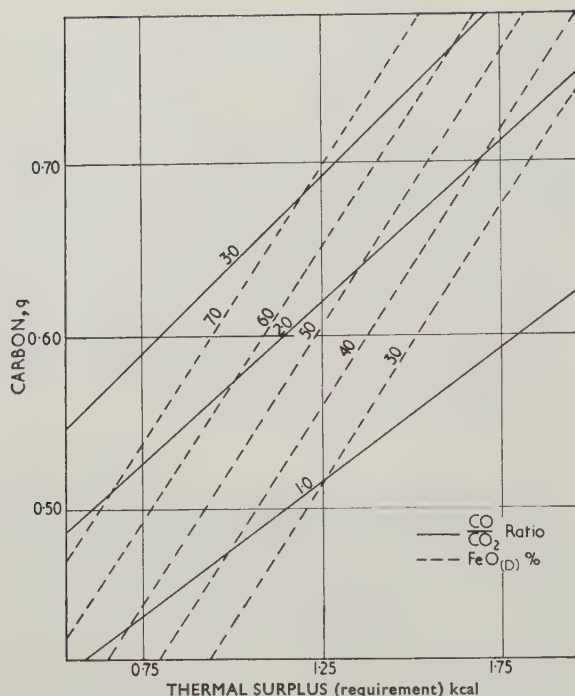
From this and similar calculations the curves shown in Fig.1 have been constructed. These show the variation rate with thermal requirements for (a) constant CO/CO₂ ratio and (b) constant degree of direct reduction in carbon of iron oxide. This latter is expressed as FeO_(D)% and is the percentage of iron reduced by coke carbon according to the equation



This method of expressing direct reduction is preferred because it is independent of the Fe/O ratio in the ore and the FeO-Fe reduction is the slow step in iron oxide reduction. It is considered therefore that reduction efficiency is more accurately reflected by the proportion of unreduced FeO than by the percentage combined oxygen reduced by CO or H₂. Figure 1 demonstrates an important aspect of blast-furnace theory, namely, that the thermal surplus, carbon rate, amount of direct reduction, and CO/CO₂ ratio are interdependent variables. If any two are specified they then determine the other two. The importance of gaseous reduction and the intercorrelation between FeO_(D), carbon rate, and CO/CO₂ ratio may be illustrated from a specific example. For a thermal surplus of 1 kcal/g Fe (a typical value for the additional thermal requirements) an improvement in FeO_(D) from 75% to 40% is required to effect an improvement in the CO/CO₂ ratio from 3.0 to 1.0 and in the carbon rate from 0.63 to 0.47 g C/g Fe. Another effect which is not always appreciated is that for a given CO/CO₂ ratio the necessary value of FeO_(D) must decrease as the thermal requirement increases. For instance if the increase is from 0.7–1.25 kcal (about the range of practical operation) the FeO_(D) value must decrease by 15–20%. In other words if the CO/CO₂ ratio is taken as the measure of thermal efficiency and FeO_(D) as the measure of operational efficiency, it requires increased operational efficiency to maintain the same thermal efficiency with increasing thermal requirements.

This raises the important question as to the criterion to be used in making comparisons: should it be constant CO/CO₂ ratio or constant FeO_(D)? The former is commonly employed but as will appear from later calculations there are cases when such a basis involves an assumed decrease in FeO_(D) which is improbable to say the least. Moreover for different cases a continual variation in FeO_(D) must be assumed for which there appears no justification. It appears in every way sounder to make comparisons in the first place on the assumption that FeO_(D), i.e. operational efficiency, remains constant. Thereafter the very difficult question of the further benefits which can be expected due to an improvement in gaseous reduction may be considered.

From the curves in Fig.1 and similar graphs for different blast temperatures the following factors for the effects of thermal requirements, degree of gaseous reduction, and blast temperature have been obtained.



Basis 1g Fe; blast temp. 800°C; top gas temp. 200°C

2 Carbon rate v. thermal requirement for coke + 10.5% oil

Thermal requirement

± 0.0324 g on carbon rate for ± 0.1 kcal on thermal requirement.

Degree of reduction

± 0.0047 g C for 600°C air blast temp. for $\pm 1\%$ FeO_(D)
 ± 0.0045 g C for 800°C air blast temp. for $\pm 1\%$ FeO_(D)
 ± 0.0043 g C for 1000°C air blast temp. for $\pm 1\%$ FeO_(D)

Blast temperature

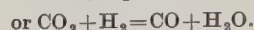
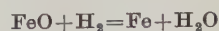
$\pm 3.75\%$ on carbon rate for $\pm 100^\circ\text{C}$ on blast temperature. This and the thermal requirement factor are for constant FeO_(D).

It should be noted that when the factor is expressed as a percentage it is based on the carbon rate corresponding to the thermal requirements of the process. In addition there is a variable amount of carbon required for solution in iron and reduction of metalloids. An average value for this would be 0.06 g. In practice therefore the corresponding amount should be deducted from the gross carbon rate before applying the percentage correction. Equally so actual CO/CO₂ ratios ought to be corrected for the CO from reduction of metalloids and CO₂ evolved from fluxes to correspond to the CO/CO₂ ratios quoted here.

Water vapour in blast

Water vapour either adventitious or deliberate is the commonest addition. Steam addition has been mainly used to modify tuyere combustion temperatures, and hence the vertical temperature gradient, in order to carry higher blast temperatures. It is almost completely dissociated in the tuyere zone by reaction with carbon and much discussion has revolved round the question of the extent to which hydrogen is reconverted to water vapour by reaction with the iron oxide

in the stack. Evidence that hydrogen (either from steam in the blast or hydrocarbon fuel) has been converted to water vapour in its passage up the furnace proves nothing since the water vapour may have formed either by



In fact the argument is an academic one if constant FeO_(D) is adopted as the basis for comparison since reduction by H₂ is equivalent to gaseous reduction by CO. It is true that the heats of reaction CO-CO₂ and H₂-H₂O are slightly different, -66 kcal and -58 kcal, and that affects the thermal balance. Calculation shows however that the effect is small enough to be ignored at least up to $\sim 10\%$ H₂ in the top gas. This also means that the CO+H₂/CO₂+H₂O ratio may be substituted for the CO/CO₂ ratio always remembering that as with CO₂ it is H₂O from reduction of iron oxide with which we are concerned and not water associated as such with the burden.

While on the basis of constant FeO_(D) the question of whether hydrogen participates in the reduction of iron oxide is an academic one, the possibility that hydrogen in the reducing gases may accelerate gaseous reduction and thus lead to a lower FeO_(D) cannot be ignored. This will be discussed later along with other possible factors which may influence the kinetics of iron oxide reduction in the blast-furnace.

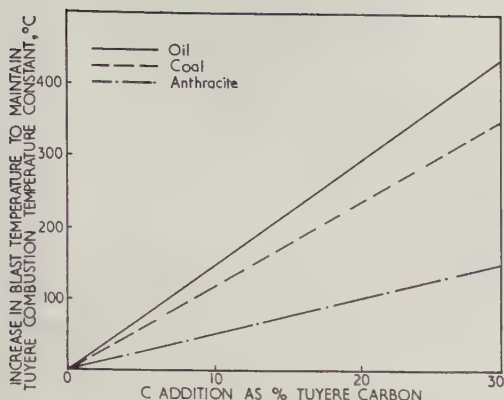
The effect of water vapour on thermal balances of the kind shown in Table I of the Appendix is straightforward and modified balances have been calculated. These were then plotted as in Fig.1 and hence the correction factor for water vapour obtained. On the basis of constant FeO_(D) it is $\pm(2.7-3.2\%)$ on carbon rate for $\pm 1\%$ moisture, the slight variation corresponds to a variation in FeO_(D) from 40-70%. On the more familiar basis of g/ft³ the correction is $\pm(0.9-1.0\%)$ on carbon rate for ± 1 gr/ft³.

There is the combined case of moisture addition compensated for by blast temperature to give the same combustion temperature. From Fig.3 1% additional moisture in the blast requires to be compensated by a 65°C rise in blast temperature. The net effect is therefore $(2.7-3.2\%) - 2.5\% = 0.2$ to 0.7% on carbon rate.

On this analysis steam additions offer no advantage, in fact slightly the reverse. It may be that the hydrogen leads to an improvement in reduction efficiency but the effect at best must be marginal and against that the cost of steam and additional blast heat must be taken into account.

Fuel additions

The possible fuels which can be used are all basically composed of carbon and hydrogen. Other constituents such as O, N, S not only contribute nothing to the fuel value but are usually deleterious. The heat of combustion of these fuels results from the burning of C and H to CO₂ and H₂O. From this must be deducted the heat required to break the C-H, C-O, C-S bonds. In general the higher the H/C and O/C ratios the greater is the deduction. The similar effects of sulphur and nitrogen can usually be ignored because of their small concentrations. The simplest way of taking this into account is to calculate the apparent calorific value of carbon from the heat of combustion of the fuel minus



3a Compensation by increase in blast temperature

the heat of combustion of hydrogen. The magnitude of this effect is shown in Table 4 of the Appendix, in which apparent calorific values per mole of carbon range from 76 kcal for methane to 96 kcal for coke and anthracite. Even more significant are the heats of combustion to CO which are 8.5 kcal and 27.8 kcal respectively. One corollary of this is that for a CO/CO₂ ratio of 2.0, which may be taken as a fairly average figure, the efficiency of utilization of carbon is about 53% for coke and anthracite but only 40% for methane. Purely from a thermal efficiency point of view therefore high carbon fuel is to be preferred.

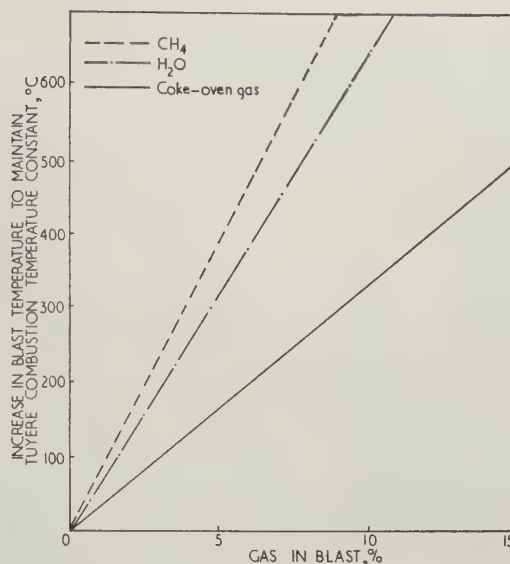
OIL

The most straightforward way of calculating the effect of oil is to determine the thermal surplus obtained if, for instance, 10% of coke carbon is replaced by 10% of oil carbon. An example of this calculation is shown in Table 2 of the Appendix for an assumed oil composition of C=86% H=12%. Although it is unnecessary when the basis of comparison is constant FeO_(D) it is convenient to calculate the values for a constant CO+H₂/CO₂+H₂O ratio. The results are then plotted as in Fig.2 which is similar to Fig.1. Reference to Table 2 of the Appendix and Fig.2 shows that in this method of calculation the real oil carbon percentage varies slightly, but for a fairly wide range of FeO_(D) 40–70% the variation is only 10.6–10.3% and may be ignored. The oil carbon expressed as a percentage of tuyere carbon is required to estimate the compensat-

TABLE 1 Effect of oil injection

Fuel	Total C, g	Oil C, g	Change in Total C, g	Coke C, g	CO+H ₂ from CO ₂ +H ₂ O	H ₂ oil, %
Coke	0.52	...	...	...	1.5	...
Coke+10.5% oil	0.53	0.056	+0.01	-0.046	1.8	3.5
Coke+10.5% oil temp. compensated (+190°C)	0.49	0.052	-0.03	-0.082	1.6	3.5
Coke+29% oil	0.545	0.158	+0.025	-0.133	2.3	10
Coke+29% oil temp. compensated (+530°C)	0.43	0.125	-0.09	-0.215	1.6	10
Coke+10.5% oil compensated O ₂ (24.2%)	0.55	0.056	+0.03	-0.026	1.9	4
Coke+29% oil compensated O ₂ (34.4%)	0.605	0.175	+0.085	-0.090	2.75	12

Thermal requirement 0.9 kcal/g Fe, blast temperature (basic) 800°C, FeO_(D) 55%



3b Compensation by increase in blast temperature

ing increase in blast temperature from Fig.3(a). This must of course vary with FeO_(D) and it is necessary to obtain the value by interpolation from the values given in Table 2 of the Appendix and similar tables.

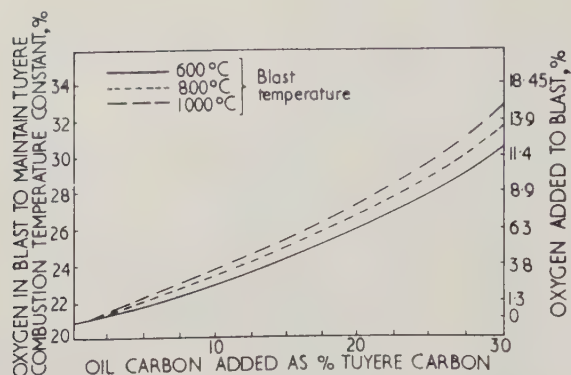
To illustrate the effect of oil additions it is necessary to take specific cases. It was first shown that the comparison was substantially independent of the assumed blast temperature, thermal requirements, and FeO_(D) value. It was also confirmed that the factors previously found for the effect of blast temperature FeO_(D) etc. were the same as for the standard case. The comparison shown in Table I was then made. From Table I the following oil/coke equivalents on a carbon basis are obtained:

Oil addition, not compensated, 1.2 oil carbon replaces 1 coke carbon

Oil addition, temperature compensated, 0.62 oil carbon replaces 1 coke carbon.

If both oil and coke are assumed to contain 86% carbon the above ratios are valid for oil and coke on a weight basis. These ratios are substantially independent of the amount of oil used. They illustrate the fact that the principal advantage derived from the use of oil is the ability to carry higher blast temperatures. Of itself oil is inferior to coke as a blast-furnace fuel as shown by the gas ratios in Table I, column 6. For the temperature compensated cases the gas reduction ratio remains unaltered, showing that in these cases the comparison based on constant gas reduction ratio and constant FeO_(D) are the same.

An alternative method of compensating for oil additions and maintaining constant tuyere combustion temperature is by oxygen enrichment. One effect of this is that less heat is supplied as preheated nitrogen. The effect on the thermal balance will therefore depend on blast temperature. The reduction in the sensible heat supplied by the blast due to oxygen enrichment is greater at higher blast temperatures. To describe fully the effects of oxygen compensation would require a series of calculations at different blast temperatures and different top gas temperatures. In the present instance the effect has been worked out at the



4 Oxygen compensation for oil injection

one blast temperature, 800°C, as an example. As in the case of temperature compensation the calculations were based on maintenance of constant combustion temperature. The required oxygen concentrations were taken from Fig.4 and an example of the calculation is shown in Table 3 of the Appendix. Graphs similar to Figs.1 and 2 were prepared and from these the values shown in Table I obtained.

It is clear from these figures that, on the basis of constant reduction efficiency, a combination of oil and oxygen is much less attractive than oil compensated by temperature. The replacement ratio is 2.0 for the former as against 0.62 for the latter case. The oxygen compensated value will be greater at higher and smaller at lower blast temperatures but the effect is not large enough to invalidate the general comparison.

It is frequently claimed that oil injection improves gaseous reduction and results based on constant $\text{FeO}_{(D)}$ represent therefore the minimum that can be expected. Variables which may affect the kinetics of iron oxide reduction are transit time of ore through the gaseous reduction zone, concentration of reducing gases, and concentration of hydrogen in reducing gases. The latter values may be obtained from data such as are represented in Table II and Figs.1 and 2. For a constant rate of iron production and unchanged size of gaseous reduction zone the change in transit time may be estimated from the change in coke rate and the burden coke ratio on the volume basis. For example, for a mainly sinter burden, if the burden/coke ratio by weight is 2.5, the bulk density of sinter 110 lb/ft³ and coke 30 lb/ft³ the burden coke ratio by volume is 0.7, then

$$\% \text{ increase in transit time} = \frac{\% \text{ decrease in coke rate}}{0.7}$$

Values calculated on this basis are shown in Table II* together with gas volumes and gas compositions.

In order to evaluate the effect of the variables shown in Table II on operational efficiency, consideration must be given to the kinetics of iron oxide reduction in the blast-furnace. This problem has been intensively studied in the laboratory⁴⁻⁶ and, while application of the results to blast-furnace conditions presents many difficulties, it seems probable that the rate controlling steps are:

* It should be noted that in this calculation the coke rates previously quoted should be amended to include the requirements for carbon solution in iron and reduction in metalloids. An average figure for these is 0.06 g.

TABLE II Factors influencing the kinetics of iron oxide reduction (oil injection)

Fuel	Increase in transit time, %	Top gas volume, litre	$\text{CO}(\text{CO}_2) + \text{H}_2(\text{H}_2\text{O})$, %	$\text{H}_2(\text{H}_2\text{O})$ from oil, %
Coke	...	2.4	43	...
Coke + 29% oil temperature compensated (+530°C)	53	2.1	43	10
Coke + 29% oil, O_2 compensated	23	2.1	60	12

Approximate values for smaller oil additions can be obtained by linear interpolation.
Thermal requirement 0.9 kcal/g Fe, blast temperature 800°C, $\text{FeO}_{(D)}$ 55%

- mass transfer by gaseous diffusion through pores in the solid particle
- mass transfer by diffusion in the solid state.

Gaseous diffusion is almost certainly rate controlling in the earlier stages but as reduction proceeds there is a gradual changeover until solid diffusion becomes the rate controlling step. The stage in the reduction process when the emphasis changes, and therefore the relative importance of the two steps, depends on type of ore and size of particle. For porous ores and large particles gaseous diffusion is relatively more important than for small particles and dense ores. In the case of gaseous diffusion mass transfer is proportional to the concentration difference for the reaction product (CO_2 , H_2O) between the gas stream and inside of the particle, the diffusion coefficient (a) and the time. That is to say the amount should increase with, concentration of reacting gas (decrease in concentration of nitrogen), (b) H_2 , H_2O content because of the higher diffusion coefficient of H_2O in relation to CO_2 , and (c) decrease in transit time of the ore. In the case of solid diffusion only transit time is important.

For the examples quoted in Table II an increase in rate for the earlier stages of reduction can be expected for oil addition, temperature compensated, because of the increase in hydrogen concentration. This should be more pronounced in the case of oil addition, oxygen compensated, because there is also an increase in the total concentration of reacting gas. The magnitude of the benefit will vary with the nature of the burden and quantitative assessment seems impossible at this stage. It may be noted however that the rate of reduction of FeO decreases as reduction proceeds so that difference in degree of reduction becomes less as the amount of unreduced FeO decreases. Furthermore, the more efficient the operation is initially (the lower $\text{FeO}_{(D)}$), the more probable it is that reduction is controlled by diffusion in the solid state and the more difficult it will be to improve gaseous reduction by alterations in gas composition. Some improvement in gaseous reduction is to be expected for the change in gas composition but, particularly when operation is already highly efficient, it is considered that the improvement will be small.

Increase in transit time should improve gaseous reduction whether gaseous diffusion in pores or solid diffusion is rate controlling. It should be possible to arrive at a factor for this from a study of operational data. Attempts to do this have not been successful; indeed some data showed gaseous reduction decreasing with increase in transit time, presumably because of

TABLE III Effect of low grade coal

Fuel	Total C, g	Coal C, g	Change in Total C, g	Coke C, g	$\frac{CO+H_2}{CO_2+H_2O}$	$\frac{H_2}{\text{from coal, \%}}$
Coke	0.52	...	...	...	1.5	...
Coke+10.3% coal	0.54	0.055	+0.02	-0.035	1.75	1.5
Coke+10.3% coal, temp. compensated (+150°C)	0.51	0.05	-0.01	-0.06	1.6	1.5
Coke+32.8% coal	0.58	0.019	+0.06	-0.13	2.35	5
Coke+32.8% coal, temp. compensated (+480°C)	0.485	0.16	-0.035	-0.195	1.6	5
Coke+10.3% coal (24% O ₂)	0.55	0.05	+0.03	-0.025	1.8	2
Coke+32.8% coal compensated O ₂ (33.8%)	0.64	0.21	+0.12	-0.09	2.7	7.5

Thermal requirement 0.9 kcal/g Fe, blast temperature (basic) 800°C, FeO_(D) 55%

unaccounted-for variations. We have analysed data from a number of different furnaces and the lowest FeO_(D) values, 40–45%, are for well-prepared burdens with a high proportion of self-fluxing sinter even when the rate of driving is high. This would show that burden preparation is more important than transit time in determining the efficiency of gaseous reduction. Increased transit time ought to improve gaseous reduction, but such evidence as exists suggests that the extent could easily be exaggerated. The sound view is to calculate coke savings from oil additions on the basis of unchanged operational efficiency. These should represent minimum values; any additional savings from increased efficiency are likely to be much less important and can only be demonstrated by operational trials.

Increased transit times can also be regarded from the point of view of possible increases in rate of production. For the two cases quoted in Table II if transit times are the limiting factor production rates could be increased 53 and 23%. However gas flow rates are also an important factor in rate of production and on this basis production rates could only be increased by 12%. The comparatively small decrease in gas volume in the case of oil and oxygen may seem surprising but it reflects the fact that, on the basis of the same FeO_(D) value, the CO/CO₂ ratio is much increased and this largely offsets the reduction in volume due to lower nitrogen. For the cases quoted in Table II an increased rate of production should be possible but the amount would depend upon the extent to which transit time or gas flow are the limiting factors.

Coal

The changes to be expected from the injection of powdered coal can be evaluated in precisely the same way as has been done for oil. Coal is much more variable in composition than oil and as examples anthracite and low-grade coal have been considered. The assumed compositions were:

	%C	%H	%O
anthracite	93	3.5	2.0
low grade coal	77	5.5	15.0

Anthracite is so similar to coke that it can be taken as

TABLE IV Factors influencing the kinetics of iron oxide reduction (low-grade coal)

Fuel	Increase in transit time, %	Top gas volume, litre	CO(CO ₂) + H ₂ (H ₂ O), %	H ₂ (H ₂ O), from coal, %
Coke	...	2.4	43	...
Coke+32.8% coal, temp. compensated (+480°C)	48	2.4	44	5
Coke+32.9% coal, O ₂ compensated (33.8%)	22	2.4	61	7.5

Thermal requirements 0.9 kcal/g Fe, blast temperature 800°C, FeO_(D) 55%

equivalent, i.e. the replacement ratio is 1. The effect on the combustion temperature is small so that the permissible or required increase in blast temperature is also small (see Fig. 3a). Fully temperature-compensated the replacement ratio for anthracite is 0.8.

The effect of the low-grade coal is illustrated in Table III.

From Table III the following coal/coke equivalents on a carbon basis are obtained

Coal addition, not compensated	1.5 coal carbon replaces 1 coke carbon
Coal addition, temperature compensated	0.83 coal carbon replaces 1 coke carbon
Coal addition, oxygen compensated	2.2 coal carbon replaces 1 coke carbon.

If the combined ash and moisture in coal and coke are assumed to be the same the corresponding values on a straight coal coke basis are:

2.0 1.1 and 2.9

These ratios are less favourable than for oil but the coal is a much lower grade fuel. The calorific values, oil and coal, are about 1.75:1, so that replacement ratios for the uncompensated and temperature compensated cases correspond to the calorific values. On the same basis coal with oxygen compensation is more favourable or less unfavourable than oil.

The factors which could influence the kinetics of iron oxide reduction and therefore operational efficiency are summarized in Table IV.

The main differences as compared with oil additions are that the hydrogen content of the gas is lower and the top gas volumes are rather higher. Any improvement in gaseous reduction due to hydrogen will therefore be less and the limiting effect of top gas volume on production rates will be greater.

Coke-oven gas

Coke-oven gas has attractions as a blast-furnace additive because it is readily available and the changing pattern of the iron and steel industry threatens to restrict its uses and therefore its value in iron- and steelworks. Apart from the relatively small methane content, coke-oven gas has little value as a fuel in the blast-furnace. H₂ and CO can take part in the reduction of iron oxide but only at the expense of the CO from the combustion of coke unless the proportion of gaseous reduction is increased. It is as a compensating addition enabling the use of higher blast temperatures that it promises to be most useful.

TABLE V Effect of coke-oven gas injection

Fuel	Total C, g	Methane C, g	Change in Total C, g	Coke C, g	CO+H ₂ CO ₂ +H ₂ O	H ₂ from coke-oven gas, %
Coke	0.52	...	...	...	1.5	...
Coke+5.3% coke-oven gas	0.55	0.03	+0.03	0	2.5	8.5
Coke+5.3% coke, temp. compensated (+400°C)	0.465	0.025	-0.055	-0.08	2.0	8.5
Coke+5.3% coke, oxygen compensated (O ₂ =30%)	0.585	0.03	+0.065	+0.035	2.7	11

Thermal requirements 0.9 kcal/g Fe, blast temperature 800°C, FeO_(D) 55%

The case for coke-oven gas of a nominal composition

%	CH ₄	CO	H ₂	N ₂	O ₂	CO ₂	H ₂ O	Cn Hm
	24	8	54	8	0.5	2.0	1.5	2

has been worked out and the results summarized in Table V. There the addition is expressed as methane carbon/total carbon. The carbon in the 'unsaturateds' should react with CO₂, H₂O, O₂ to give CO+H₂. It is more usual to express such additions as volume of gas/volume of air. The relation between the volume of air blown and the carbon rate varies with the efficiency of the furnace and in addition the metered air to the blast-furnace is a notoriously unreliable figure. No general conversion figure can be given but for the examples quoted in Table V the gas addition of 5.3% corresponds to 12% of true air volume. One useful advantage of expressing the addition as methane carbon/total carbon is that for the non-compensated case the total carbon requirement varies very little with methane concentration. For example, for pure methane it is 0.54 as compared with 0.55 shown in Table V. Normal variations in the coke-oven gas composition may be ignored.

The results in Table V show that on the basis of the same operational efficiency coke-oven gas contributes nothing to the economy of the furnace. Unlike steam, however, it does allow the full advantage of increase in blast temperature to be realized. Combination of coke oven gas and oxygen on this basis leads to a slight increase in coke rate.

The factors which influence gaseous reduction are summarized in Table VI.

Again one can only quote these figures as no realistic assessment of the effect on gaseous reduction is possible. In one important respect they are less favourable than for oil and coal, namely, transit time. Indeed in the oxygen compensated case, transit time actually decreases. One may also note that the top gas volume increases in the temperature compensated case, which reduces the possibility of increasing the rate of production.

Comparison of the various additions considered here must be based finally on economics which are beyond the scope of this paper. There is however one technical point of some importance. The fact that the replacement ratios for anthracite and low-grade coal, temperature compensated, are almost the same is misleading. It is because in the one case a 10% addition

TABLE VI Factors influencing the kinetics of iron oxide reduction (coke-oven gas)

Fuel	Increase in transit time, %	Top gas volume, l	CO(CO ₂)+H ₂ (H ₂ O), %	H ₂ (H ₂ O), from gas, %
Coke	...	2.4	43	...
Coke+5.3% gas, temp. compensated (+400°C)	20	2.8	47	9.5
Coke+5.3% gas, O ₂ compensated (30%)	-8	2.5	59	11

Thermal requirement 0.9 kcal/g Fe, blast temperature (basic) 800°C FeO_(D) 55%

requires only a 60°C increase in blast temperature as against a 200°C in the other. The cost of the increased sensible heat in the blast should come into the comparison. For any given increase in blast temperature about three times as much anthracite as low-grade coal could be used and about three times as much coke saved. Similarly if utilization of reserve stove capacity is the primary objective coke-oven gas might be attractive but the maximum coke saving with coke-oven gas is much less than with other additions.

TUYERE COMBUSTION TEMPERATURE AND GAS-SOLID TEMPERATURE DIFFERENCES

It has been pointed out earlier that the temperature gradient in the furnace is an important factor in the blast-furnace process and that gas-solid temperature differences are a guide to this. The calculation of absolute values is impossible and hence recourse must be made to comparative data. These can be obtained by calculating gas-solid temperature differences based on knowledge of reactions taking place in the furnace for a normal case and comparing with this norm the effects of altering conditions in the furnace. As will be shown in this section, it has been found adequate to take the tuyere combustion temperature as a guide to the gas-solid temperature differences and the comparisons have been made at constant tuyere combustion temperatures.

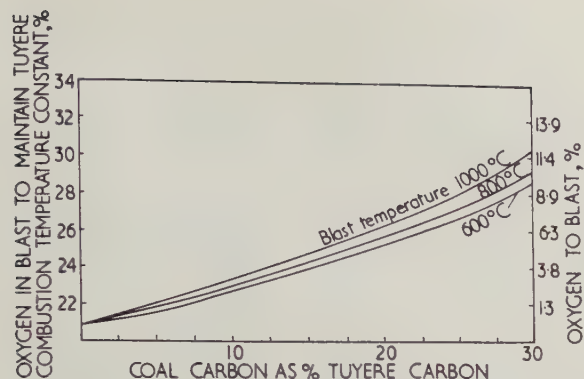
Tuyere combustion temperatures

Graphs have been prepared to give the compensating adjustments in blast preheat or oxygen enrichment necessary to maintain a constant tuyere combustion temperature when making additions of oil, coal, etc., at the tuyeres. The basis of these graphs is as follows:

- coke arriving at the tuyere zone of the furnace is at 1350°C. The actual value is relatively unimportant since we are only interested in comparative values
- coke is burned at the tuyeres to CO
- hydrogen is not oxidized in the tuyere zone
- moisture is decomposed and forms hydrogen and carbon monoxide
- oxygen added to the blast is preheated in the stoves
- the additives are injected at ambient temperature.

The thermal data on which the calculations are based are given in the Appendix along with the compositions assumed for the additive fuels.

Calculations of tuyere combustion temperatures

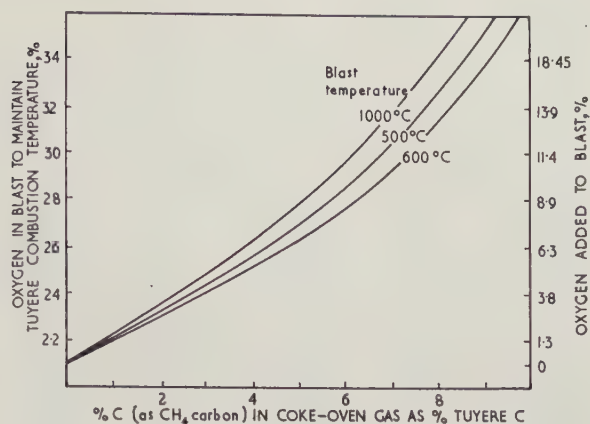


5 Oxygen compensation for coal injection

were made for different blast temperatures for coke and these figures were used as the basis on which comparisons were made. These calculations were repeated for the addition of different amounts of additives at different blast temperatures. Graphs of tuyere combustion temperature plotted against the percentage addition for different blast temperatures were constructed. From the graphs the necessary increase in blast temperature for a given amount of blast additive which would maintain a certain tuyere combustion temperature can be obtained. This increase in blast temperature is independent of the level of blast temperature and hence the results can be plotted as a graph of increase in blast temperature necessary to maintain the same tuyere combustion temperature against percentage addition of oil, coal, or anthracite. Because of the wide variations in the ratio tuyere carbon/total carbon these graphs refer to the additive as a percentage of carbon introduced in the additive to the total tuyere carbon. Hence to use these graphs the carbon burned at the tuyeres by the blast must be calculated. All the carbon in the blast additive is included in the tuyere carbon. The data are shown in Figs.3a and b. The increase in blast temperature required is directly proportional to the percentage additive carbon and is greatest in the case of oil and least in the case of anthracite. These data are for compositions assumed in Table 4 (Appendix). In the case of coke-oven gas and methane the data have been expressed as a plot of the percentage gas in the blast against increase in blast temperature.

Compensation by blast temperature is straightforward in that there is no change in blast volume per unit of carbon burned, whereas in the case of oxygen enrichment the blast volume per unit of carbon decreases. Thus in the case of oxygen enrichment the increase in tuyere combustion temperature is a result of a decrease in the volume of products and not as a result of extra heat supplied to the hearth, in fact there is a decrease in the total heat available because less heat is added as preheat in the blast. Thus oxygen enrichment means less total heat per unit of carbon burned but this heat is at a higher potential.

Calculations of combustion temperature have been made for various oxygen contents of blast with varying blast temperatures and varying additions of oil, coal, anthracite. The effect of increase in oxygen at a given blast temperature is to increase the gradient of the graph of tuyere combustion temperature against the percentage additive as the amount of additive



6 Oxygen compensation for coke oven gas injection

increases. This means that the oxygen addition necessary to maintain the tuyere combustion temperature is not directly proportional to the amount of additive introduced, but the relative increase is greater the greater the amount of additive introduced. For example, at 10% oil addition and blast temperature 600°C, 2% additional oxygen is sufficient, while for 30% oil, 9% additional oxygen is necessary. There is also a variation in oxygen enrichment necessary with differing blast temperatures, more oxygen being required the higher the blast temperature. The data for compensation by oxygen for the additive fuels, oil, coal, and coke-oven gas are shown in Figs.4-6.

Gas-solid temperature differences

In order to calculate comparative data for gas-solid temperature difference the carbon rates for the given conditions are required. Two different types of burden have been taken as examples, one an unprepared burden and the other a fully prepared one in which all the limestone has been incorporated in the sinter. The effects of increase in blast temperature and of oil additions compensated by increase in blast temperature or by oxygen enrichment have been calculated and these are compared below. The comparisons are all made at a constant value of $\text{FeO}_{(D)}$ of 55%. To calculate the carbon rate for any given burdening conditions the thermal requirements are first calculated and from these, using graphs similar to Figs.1 and 2, the carbon rate can be obtained.

Pig iron composition

C 4.0%, Si 0.5%, Mn 1.0%, P 1.0% (these are percentage Fe and not pig iron).

Slag bulk	10 cwt/ton
Limestone (in unfluxed burden)	6 cwt/ton Fe
Limestone (in fluxed burden)	Nil
Water (in unfluxed burden)	3 cwt/ton Fe
Water (in fluxed burden)	0.75 cwt/ton Fe
Temperature of iron	1427°C
Temperature of slag	1450°C
Top gas temperature	200°C

The thermal data used are given in the Appendix. The carbon required for solution in iron and reduction of metalloids must also be taken into account and the CO or CO_2 produced in these reactions and in the calcination of CaCO_3 .

Taking the unfluxed burden the thermal require-

TABLE VII Gas-solid temperature differences

Blast temp., °C	O ₂ in blast, %	Oil addition, %	Total C g/g Fe	$\frac{\text{CO} + \text{H}_2}{\text{CO}_2 + \text{H}_2\text{O}}$ over Fe ₂ O ₃		Gas-solid temperature differences					Top	Comments
				$\frac{\text{CO} + \text{H}_2}{\text{CO}_2 + \text{H}_2\text{O}}$ top gas		1350°C	1050°C	900°C	700°C			
Unfluxed burden, thermal requirements 0.93 kcal/g Fe												
600	21	0	0.634	1.9	1.66	440	225	140	60	200	} Same tuyere combustion temperature. Compensation by oxygen or increase in blast temperature	
800	21	9.5	0.598	1.9	1.67	420	245	115	15	200		
600	23.8	9.6	0.658	2.2	1.91	415	215	130	20	200		
1030	21	20.7	0.561	2.0	1.72	410	200	120	15	200		
600	32.1	26.3	0.715	3.0	2.55	400	200	120	15	200	} Higher tuyere combustion temperature	
1000	21	0	0.55	1.5	1.34	680	375	230	125	200		
Fluxed burden, thermal requirements 0.78 kcal/g Fe												
600	21	0	0.581	1.6	1.70	410	90	-10	10	200	} Same tuyere combustion temperature as majority of unfluxed data	
800	21	9.4	0.55	1.7	1.8	390	70	-30	-5	200		
600	24	9.5	0.605	1.9	2.0	385	80	-20	10	200		
1040	21	20.5	0.516	1.7	1.8	395	65	-35	-15	200		
600	32.4	26.0	0.657	2.75	2.85	380	70	-20	-5	200	} Higher tuyere combustion temperature	
1000	21	0	0.506	1.25	1.32	620	250	80	65	200		

Top gas temperature 200°C. Comparisons made at 55%FeO_(D). Slag bulk 50%.

ments are as follows, these are expressed on the basis of 1 g Fe.

	cal/g Fe	g C/g Fe	CO ₂ , l	CO, l
(1) C in iron 0.04×1058	43.3	0.04	...	...
(2) Si in iron 0.005×5250	26.20	0.0043	...	0.008
(3) Mn in iron 0.01×1014	16.14	0.0122	...	0.504
(4) P in iron 0.01×4800	48.0	0.0096	...	0.018
(5) Sensible heat CO from metalloid reduction 0.03×625	1.9			
(6) Iron 1×298	298			
(7) Slag, sensible heat 0.5×425	212.5			
(8) Slag heat of formation 0.5×100	-50			
(9) Calcination of CaCO ₃ 0.3×427	128		0.0672	
(10) Sensible heat of CO ₂ from limestone $0.3 \times 0.224 \times 86$	5.8			
(11) Radiation and cooling losses 1×100	100			
(12) Water evaporation 667×0.150	100			
	930	0.0561	0.0672	0.03

For a burden with fluxed sinter the only items altered would be (8), (9), and (10) which become zero and (12) which would be reduced to 25 cal/g Fe. The total thermal requirements then become 0.78 kcal/g Fe.

The carbon rate of any given CO/CO₂ ratio or FeO_(D) value can now be obtained from graphs constructed by the methods described in the previous section. Comparisons have been made at an FeO_(D) value of 55%. Taking as an example a blast temperature of 600°C, unfluxed burden, thermal requirements 0.93 kcal/g Fe. The carbon rate is 0.578 g C/g Fe, and the CO/CO₂ ratio over Fe₂O₃ is 1.87. To this carbon rate the carbon dissolved in the iron and in reduction of metalloids must be added which is 0.056 g C/g Fe making the total carbon 0.634 g C/g Fe. Also the CO/CO₂ ratio must be corrected for direct reduction of metalloids and carbon dioxide from limestone calcination; this can again be calculated using the data above.

$$\frac{\text{CO}}{\text{CO}_2} \text{ ratio over Fe}_2\text{O}_3 = 1.87$$

$$\text{Top gas } \frac{\text{CO}}{\text{CO}_2} \text{ ratio} = \frac{(0.414 \times 22.4)}{12} + 0.03 = \frac{(0.22 \times 22.4)}{12} + 0.0672 = 1.67$$

In the case of the fluxed sinter burden the carbon monoxide from the reduction of metalloids is the only correction required. The carbon rate for these typical burdens taking 55%FeO_(D) as the furnace operating efficiency has been calculated for different operating conditions. Gas-solid temperature differences have been calculated for the case of oil addition since it has a high hydrogen content and one would expect the maximum deviation from the normal. The data on carbon rates together with gas reduction ratios are given in Table VII. The first five data for the unfluxed and fluxed burden are for the same tuyere combustion temperature using blast temperature or oxygen to compensate for oil injection. The data for 1000°C blast and coke are for a higher tuyere combustion temperature. From these data it is possible to calculate gas-solid temperature differences for comparison.

The method of calculating gas-solid temperature differences has been described previously.² The heat absorbed by the descending stock plus radiation and cooling losses at various temperature levels are equated with the heat given out by the ascending gases. From these data gas temperatures corresponding to the chosen solid temperatures are calculated. As already pointed out lack of precise data on the course of the furnace reactions requires a number of assumptions to be made and the results must be regarded as having comparative value only.

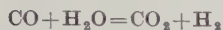
In the present calculations temperature levels in the solid of 1350°, 1050°, 900°, and 700°C have been chosen and the following assumptions made:

- (1) reduction of SiO₂, 3CaO.P₂O₅, MnO above 1350°C
- (2) slag formation and solution of carbon in iron 1050–1350°C
- (3) calcination of CaCO₃ between 700° and 900°C
- (4) gaseous reduction of Fe₂O₃ to FeO below 700°C

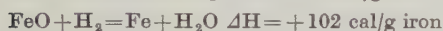
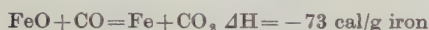
(5) gaseous reduction of FeO to Fe between 700° and 900°C

(6) radiation and cooling losses as in Appendix.

In the case of the use of additives containing a proportion of hydrogen, some of the gaseous reduction may be ascribed to hydrogen. In considering the overall balance it can be assumed that a certain final $\text{CO} + \text{H}_2/\text{CO}_2 + \text{H}_2\text{O}$ is attained but in calculating gas-solid temperature differences it would be valuable to know the amount of H_2 at different temperature levels. Thermodynamically, hydrogen is more effective than CO in a gaseous reduction at higher temperatures but at any given temperature it might be expected that the water/gas equilibrium would be the controlling equilibrium:

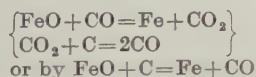


The equilibrium constant for this reaction increases with decreasing temperature but it would appear from the limited data available that concentrations in the top gas correspond to the equilibrium concentrations at about 900°C. The actual thermal changes involved in the reactions are small:



and since the calculated data are only useful for comparative purposes all the gaseous reduction of ferrous oxide is assumed to take place between the 700° and 900°C temperature levels. Any conversion of hydrogen to water vapour is assumed to take place in this zone and the gaseous reduction of Fe_2O_3 is all ascribed to carbon monoxide.

The most difficult reaction to apportion is the direct reduction of ferrous oxide which can take place by two mechanisms



The first is probably the main mechanism while the burden is solid but once primary slag formation commences the second reaction can take place rapidly. The first mechanism would only appear to be important above 850–900°C while the second only becomes important once slag formation commences, i.e. above 1050°C. As in the earlier paper,² one third of the direct reduction has been ascribed to the 900°C to 1000°C temperature zone and the remainder to the 1050–1350°C zone. This is at the best an intelligent guess but it should again be emphasized that the results are only being used for comparative purposes.

The results given in Table VII are the calculated data for different burdening conditions. A specimen calculation is shown in the Appendix together with the thermal data on which it is based.

Considering first the calculated results for the raw ore burden, the norm is the data for the 600°C blast temperature with air blast and all coke fuel and the other data are to be compared with it. Two calculations have been made to illustrate the effect of oil additions compensated by increase in blast temperature. There is no significant difference between these values of the gas-solid temperature differences at the 1350°, 1050°, and 900°C levels and those for the norm. At the 700°C level the values are a little lower than the norm.

The carbon rates shown in Table VII show a decrease for the case of oil compensated by increase in blast temperature. Consideration of gas-solid temperature differences, which show a slight decrease at the lower temperature levels, suggest that either (a) the top gas temperature will rise slightly, or (b) the blast temperature may be raised further. In the first case this would result in slight increase in carbon consumption and in CO/CO₂ ratio. To bring the gas-solid temperature differences at 700°C to the norm would only require an additional 0.01 g C/g Fe. On this basis the calculated improvement in carbon rate would be a maximum unless there was improved gaseous reduction. In the second case if stock movement permitted the increased gas-solid temperature difference at the higher temperature levels a further lowering of carbon rate would be possible. In this case the temperature compensation for oil additions on the basis of constant tuyere combustion temperature would be a minimum. But it should also be pointed out that these effects are marginal; if the change in gas-solid temperature differences resulting from oil additions are compared with those resulting from an increase in blast temperature shown in Table VII the magnitude of the effect can be seen.

In considering the fluxed burden it should be again pointed out that the gas-solid temperature differences calculated are not absolute values and no great significance should be attached to the negative values shown in Table VII. Similar considerations apply when the data for fluxed burdens and temperature compensation are compared within themselves as for the case of the unprepared burden. Again the higher temperature levels show little change in gas-solid temperature differences and there is a slight lowering at the 900° and 700°C level, the relative significance of which has been discussed above.

Calculations showing the effect of using oxygen compensation for oil additives are also given in Table VII. As far as gas-solid temperature differences are concerned the same trend appears as with blast temperature compensation, but again the effect is small. The only revision which a consideration of the figures would suggest would be (a) the top gas temperature might increase slightly, or (b) less oxygen enrichment should be used than that calculated from maintenance of tuyere combustion temperature. In the case (a) carbon consumption would be slightly increased; in the case (b) carbon consumption slightly decreased. The carbon rates and CO/CO₂ ratios with oxygen compensation are higher than for blast temperature compensation as has been shown above.

Similar considerations would apply to the use of coal or anthracite. One would expect these to show smaller deviations from the norm than oil since they have higher C/H ratios. The effects of coke-oven gas have been previously shown² to be similar and here also tuyere combustion temperature is a guide to gas-solid temperature differences.

The effect on the gas-solid temperature differences of changing from an unprepared burden to a self-fluxing one can be seen from the data in Table VII. Examination of the data show that the relative effects (in changing from unfluxed to fluxed burdening) are the same irrespective of blast temperature, oil addition or oxygen enrichment. Hence we can draw conclusions which apply to all conditions. At the

TABLE VIII Correction factors for fuel injection

<i>Fuel replacement values—not compensated</i>	
1.2 oil carbon equivalent to 1 coke carbon	
1.0–1.5 coal carbon equivalent to 1 coke carbon: range of coal composition 93–77% C	
3 methane carbon equivalent to 1 coke carbon	
2 natural gas carbon equivalent 1 coke carbon	
<i>Other correction factors</i>	
±100°C on blast temperature	±3.75% on carbon rate
±1% moisture in blast	±2.7–3.2% on carbon rate (40–70% FeO _(D))
±100°C on top gas temperature	±4.9% on carbon rate
±0.1 kcal on thermal requirement	±0.0324 g on carbon rate/g Fe
±1 cwt on slag (ore + limestone burden)	±0.17 cwt on carbon rate/ton pig
±1 cwt on slag (fluxed sinter)	±0.13 cwt on carbon rate/ton pig
The last two items are derived from the previous one by assuming average basic iron burdens and composition	

Basis—Constant FeO_(D)

1350°C level the gas–solid temperature differences are not significantly different but at the other levels they are significantly lower in the case of fluxed burden. If the gas–solid temperature differences for the unfluxed burden were the minimum at which the furnace would operate smoothly then one would expect the top gas temperature in the case of the fluxed burden to be higher, hence increasing temperature differences at the higher levels of the furnace. This would either result in slightly increased carbon consumption, or what would be more attractive, allow an increased blast temperature to be carried. The possibilities of carrying higher blast temperatures with a fluxed burden are also indicated by a comparison of the norm for unfluxed burdens with that for a 1000°C blast temperature and a fluxed burden. The gas–solid temperature difference at the 1350°C level is greater with the higher blast temperature but at the other levels the temperature differences are similar. One reason why high blast temperatures cause poor stock descent is that the increased temperature gradient results in a narrowing of the slag fusion zone. In the case of a fluxed sinter burden gas–solid temperature differences are lower and this together with the fact that the slag is preformed should permit higher blast temperatures. The tendency for the gas–solid temperature differences at the 900° and 700°C levels to be lowered in the case of fluxed burdens may result in a widening of the gaseous reduction zone in the furnace which is of course a desirable aim. This would suggest that where a furnace is working on a burden composed of 100% fluxed sinter and operating at its highest efficiency the blast temperature will be higher than would be the case with a raw ore-charge. It has been shown here that where blast additives such as oil are used the most attractive combination is fuel with blast temperature compensation. This would mean that in the case of fluxed burdens because the scope for increasing blast tem-

perature is less, the possible benefits to be obtained from additive fuels would be less. The amount of gaseous reduction in fluxed burdens may also be greater than in unprepared burdens and if there are any benefits due to increase in gaseous reduction these would also be more difficult to achieve. The higher the efficiency at which a furnace is working the smaller would appear to be the improvement possible from the use of additive fuels.

All the comparisons have been made at a fixed value of FeO_(D) but the conclusions are equally applicable if the value of FeO_(D) is altered since the effect of changes in FeO_(D) on gas–solid temperature differences is negligible. It has been shown that the tuyere combustion temperature is a guide to gas–solid temperature differences and that little amendment is required to the carbon rates calculated in the first section. This will also hold even if there is an improvement in gaseous reduction from the use of fuels containing larger amounts of hydrogen.

GENERAL DISCUSSION

The greatest uncertainty in connexion with the theoretical treatment of this subject is the extent to which the operating efficiency of the furnace may be modified by fuel injections. One approach to this problem is to examine operational results in the light of the factors derived from the theoretical study. We have examined several data in this manner, those obtained in the experimental furnace of the US Bureau of Mines,⁷ the low shaft furnace at Liège,⁸ and a number of full-scale trials in America.^{9–12} For ease of reference the factors derived earlier in the paper together with one or two extra ones required for the analysis are grouped together in Table VIII.

The correction factors listed in Table VIII have been used to analyse the data in Table III of the US Bureau of Mines results.⁷ In these data period 2 is the reference period and the estimated changes due to blast temperature, moisture, top gas temperature, and natural gas injection have been evaluated and compared with the observed change in coke rate (Table IX). The net coke rate for period 2 (gross minus carbon solution and reduction of metalloids), on which the percentage changes are based, is 1300 lb. Periods 1, running in, 6 and 8, unused methane in top gas, and 10, oxygenated blast, have been omitted from the analysis.

The relatively small difference between the observed and calculated values for natural gas injection indicates that the improvement in gaseous reduction is small. The difference is rather larger in the case of steam additions largely because of the results for period 4. If the additional decreases in coke rate are

Table IX Calculated and observed changes in coke rate for experiments described by Ostrowski et al.⁷ (1d coke per ton iron)

Period	High moisture		5	Natural gas		11	12	13	14	15
	3	4		7	9					
Correction for blast temperature	–78	–182	–182	–182	–182	–182	–216	–78	–78	–78
Blast moisture	+78	+255	+209	+11	+11	–11	–36	–18	–36	–36
Top gas temp.	–25	–46	–55	–17	–27	–25	–25	–15	–34	–27
Natural gas	...	...	...	–68	–52	–58	–67	–16	–18	–17
Calculated total	–25	+27	–28	–256	–250	–276	–344	–127	–166	–158
Observed	–42	–104	–89	–347	–307	–307	–352	–167	–157	–152
Observed–calc.	–17	–141	–61	–91	–57	–31	–12	–40	+9	+6
Mean difference		–73					–29			

all ascribed to increase in gaseous reduction they would correspond to decreases in $\text{FeO}_{(D)}$ of 3% and 8%, respectively. In fact if $\text{FeO}_{(D)}$ is calculated from the carbon balance it is virtually constant at 50%, except for periods 4 and 7, which were down to 40 and 43%, respectively. The apparent decreases in $\text{FeO}_{(D)}$ are due to the fact that increase in blowing rate on this small furnace has a significant effect on the cooling losses per ton of iron and in the above analysis no correction has been made for this variation. The agreement therefore between calculated and observed values should be even better than shown in Table IX. The apparently better results for steam injection are rather surprising but, as pointed out above, they are strongly influenced by the one exceptional result for period 4. These results stress one factor which has not previously been considered, namely, top gas temperature. Due to the lower top gas temperatures there is an average decrease in coke rate of 42 lb and 24 lb respectively, for the high moisture and natural gas series. Top gas temperature is however influenced by a number of factors and while it may appear significant that in all cases the top gas temperature is lowered, that could be because the temperature in the reference case is unduly high. The evidence of other trials is far from conclusive in this respect; sometimes top gas temperature rises and sometimes it falls.

We have also examined the results of oil injection experiments in the low-shaft furnace at Liège,⁸ and trials with natural gas injection on a number of operating furnaces in America.⁹⁻¹² In contradistinction to the Bureau of Mines experiments, in all but one case the calculated reduction is considerably less than the observed. The average difference between calculated and observed for 11 sets of data is 110 lb coke/short ton, which represents a substantial improvement in gaseous reduction. The one exception is Fairless,¹¹ where the calculated and observed are virtually the same. It may be significant that in the latter case the initial operation is quite efficient whereas in several other cases gaseous reduction in the reference period is poor. A repeat of the results for the reference conditions after the fuel injection experiments would have been a valuable check.

Lack of agreement among the available data does not permit a clear answer to the question of whether gaseous reduction is improved by hydrocarbon injections. They do however tend to confirm our view that, when reduction efficiency is already high, further improvement due to injections is likely to be marginal and the factors derived on the basis of constant $\text{FeO}_{(D)}$ should be applicable.

Consideration of gas-solid temperature differences leads to the conclusion that tuyere combustion temperature alone ought to be a sufficient guide to the compensating adjustments necessary to maintain the same operational conditions. This conclusion can be tested in the light of experimental results. Only the US Bureau of Mines results can be used for this purpose because only in their series of experiments was an attempt made to raise the blast temperature to the maximum consistent with satisfactory operation. For the results in Table IX the recorded blast temperature is only some 11°F greater than that calculated for full compensation, which confirms our calculations. There is however considerable fluctuation and the results

fall into two groups, 3, 12, 13, 14, 15 and 4, 5, 7, 9, 11. In the former the average blast temperature is 117°F greater than calculated and in the latter 107°F less. Significantly for these two groups the average $\text{FeO}_{(D)}$ values are 52 and 48% and the coke savings in excess of the calculated are 11 and 76 lb respectively.

These results illustrate a very important point. In normal operation the blast temperature may be varied within wide limits. If the blast temperature is pushed to the limit that the furnace will take it is certain that before that limit is reached there must be some loss in operation efficiency because of poorer stock descent. This means that as the limit is approached the full benefit of increase in blast temperature is not being realized. Lowering the tuyere combustion temperature by fuel additions could restore smoother stock movement and improve reduction efficiency. In effect the fuel addition is enabling the operator to realize the full benefit of the blast heat. The benefits to be derived from fuel additions must depend therefore to some extent on standard practice at the particular plant. Some operators emphasize smooth operation with rather modest blast temperatures, others favour the maximum possible blast temperature. Initially the latter ought to get a better replacement ratio for fuel additions than the former because he has been pushing blast temperature to the stage where he is ceasing to get the full benefit, but that should hold only for the initial additions.

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APPENDIX

TABLE 1 Example of thermal surplus calculation

Reduction of Fe_2O_3 for $\text{CO}/\text{CO}_2 = 2.0$. Basis 1 g mole Fe		
Proportion of reactions A, B	100% A	50/50 A, B
Coke carbon total (tuyere) mole	4.5 (4.5)	2.81 (2.25)
$\text{FeO}_{(D)}$, %	0	56
Heat of reaction, kcal	128.3	43.3
Combustion air, l	240	120
Top gas total (CO_2), l	290 (33.6)	162 (22.4)
Sensible heat air, kcal at 600°C	46.8	23.4
800°C	63.6	31.8
1000°C	81.0	40.5
Sensible heat top gas, kcal at 200°C	19.0	10.7
Total thermal surplus for top gas 200°C and air T°, kcal 600°C	156	56
800°C	173	64.5
1000°C	190.5	73

TABLE 2 Oil injection

	C	H	C/H
Assumed composition	86	12%	1.2
Changes in values of Table I for a 10% replacement of coke carbon by oil carbon at a $\text{CO} + \text{H}_2/\text{CO}_2 + \text{H}_2\text{O} = 2$			
Proportion of reactions A, B	100% A	50/50 A, B	
Coke carbon mole	4.05	2.53	
Oil carbon mole	0.45	0.28	
Hydrogen mole	0.375	0.233	
$\text{H}_2(\text{H}_2\text{O})$ from oil, l	8.4	5.2	
Difference in CV oil—coke carbon, kcal	-2.7	-1.7	
Heat due to H_2 in top gas, kcal	-0.5	-0.3	
Heat from $\text{Fe}_2\text{O}_3 + \text{H}_2$, kcal	-1.0	-0.6	
Coke carbon required, mole	-0.37	-0.143	
Air required, l	-20	-6.1	
Heat from coke carbon kcal, at blast temp.			
600°C	-13	-2.9	
800°C	-14.3	-3.3	
1000°C	-15.8	-3.7	
Actual oil carbon, %	10.9	10.5	
Actual oil carbon, % referred to tuyere carbon, %	10.9	13.0	
$\text{FeO}_{(D)}$, %	0	53	

TABLE 4 Thermal data for fuels

Fuel	Assumed composition	Heat of combustion to carbon monoxide cal/mole C	cal/g C	Heat of combustion to carbon dioxide cal/mole C	cal/g C
Coke		27800	2315	95400	7950
Fuel oil	Carbon:hydrogen ratio 86:12	21800	1815	89400	7450
Low grade coal	C-77%, H-5.5%, N+S-2.5%, O-15%	16400	1365	84000	7000
Anthracite	C-93%, H-3.5%, N+S-1.5%, O-2%	28400	2365	96000	8000
Methane		8530	381*	76170	3400*

* cal/l methane

TABLE 5 Heats of formation

Com-pound	Equation	Heat of formation cal/mole compound	cal
FeO	$\text{Fe} + \frac{1}{2}\text{O}_2 \rightarrow \text{FeO}$	-63500	-1132 (g Fe)
Fe_2O_3	$2\text{Fe} + \frac{3}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$	-196200	-1750 (g Fe)
SiO_2	$\text{Si} + \text{O}_2 \rightarrow \text{SiO}_2$	-209600	-7480 (g Si)
MnO	$\text{Mn} + \frac{1}{2}\text{O}_2 \rightarrow \text{MnO}$	-92050	-1672 (g Mn)
$\text{Ca}_3\text{P}_2\text{O}_8$	$3\text{CaO} + \text{P}_2 + \frac{3}{2}\text{O}_2 \rightarrow \text{Ca}_3\text{P}_2\text{O}_8$	-517000	-8350 (g P)
H_2O	$\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}_{(g)}$	-57798	-3210 (g H_2O)
H_2O	$\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}$	-68317	-3800 (g H_2O)
CaCO_3	$\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3$	-42700	-427 (g CaCO_3)

TABLE 7 Radiation and cooling losses

Heat of formation of slag	100 cal/g slag
Radiation and cooling losses	
100 cal/g Fe for 20 ft furnace making 5400 tons iron/w	
Best assumption for others	$\frac{27000 \times \text{hearth dia.}}{\text{weekly output in tons}}$ cal/g Fe
Distribution in zones	
1350°C to hearth	50%
1050°C to 1350°C	30%
900°C to 1050°C	10%
	900°C to 700°C 5%
	700°C to top 5%

TABLE 9 Sensible heat of pig iron

Sensible heat of pig iron at 1427°C	
(composition 4% C, 1% Mn, 0.5% Si, 1% P)	
Iron	231 cal/g Fe
Carbon 550×0.04	22
Carbon solution -508×0.04	20.3
Phosphorus 1300×0.01	-13
Manganese 444×0.01	4.44
Silicon -250×0.005	-1.25
Heat of fusion of iron	66.0
Total	329.50 cal/g Fe

TABLE 3 Oil injection with oxygen compensation

Nominal 10% oil, oxygen compensated to give constant flame temperature. Effects supplementary to those given in Table II.

Proportion of reactions A, B	100% A	50/50 A, B
O_2 in air, %, for blast temp.		
600°C	23.3	23.8
800°C	23.5	24.1
1000°C	23.8	24.4
Change in air volume, l (N_2)		
600°C	-22	-12
800°C	-24	-13
1000°C	-26	-14
Heat content blast, kcal		
600°C	-2.6	-1.7
800°C	-4.6	-2.9
1000°C	-6.8	-4.2

TABLE 6 Heats of solutions and fusion

Element	Notes	Heat of solution in iron, cal/g element	Heat of fusion cal/g element
Iron		...	66
Manganese		...	63.8
Carbon	Coke carbon	-508	...
Silicon		1000	...
Phosphorus	Approximate	1600	...

TABLE 8 Sensible heats

Material	Sensible heat, cal/g	1450	1427	1350	1050	900	700	°C
Iron	...	232	216	169.5	143	100		
FeO	246	187	156	188		
Carbon	574	550	525	464	212	224		
$3\text{CaO.P}_2\text{O}_8$	1770	1430	1080	752	(/g P)	
SiO_2	766	880	488	370	(/g Si)	
MnO	308	235	196	148	(/g Mn)	
Slag constituents	388	284	239	176		
CaCO_3	177		
Molten slag	425	...	...	...	...	...
Silicon	...	750	...	...	...	...
Phosphorus	...	220	...	...	...	...
Manganese	...	318	...	...	...	...

CALCULATION OF GAS-SOLID TEMPERATURE DIFFERENCES

Blast temperature 600°C	
Carbon rate 2.952 mole/mole Fe	$\text{FeO}_{(D)}$ 55%
CO/CO_2 ratio 1.66	Slag volume 50%
Tuyere carbon 2.15 mole/mole Fe	Metal temperature 1427°C
Air volume 114 l/mole Fe	Slag temperature 1450°C
Tuyere gas volume 138 l/mole Fe	

TABLE 10 Total heat of stock on basis of one mole Fe

Constituent	Sensible heat in kcal/mole Fe				
	Hearth	1350°C	1050°C	900°C	700°C
Iron	18.47	18.12	5.97	3.6	...
Iron oxide	...	...	4.98	6.17	8.5
Carbon	14.8	14.0	12.70	11.10	7.95
Slag	11.9	10.5	...	...	...
Calcium phosphate	...	1.0	0.8	0.6	0.42
Slag constituents	...	...	7.95	6.7	3.27
Calcium carbonate	...	...	...	...	2.97
Total	45.17	43.62	32.4	28.17	23.11

TABLE 12 Gas temperatures

Tem- perature level	Heat in gases, kcal	Volume of gases, l	Sensible heat of gases, cal/l	Gas temp., °C	Gas-solid temp. difference, °C
1350°C	87.74	139.7	630	1790	440
1050°C	64.44	147.9	435	1275	225
900°C	53.23	152.0	350	1040	140
700°C	42.53	155.76	273	760	60
Top	12.74	166.26	76	210	210

TABLE 11 Heat absorbed between temperature levels and hearth

	Heat in kcal/mole Fe				
	1350°C	1050°C	900°C	700°C	Top
Difference in stock heats	1.55	12.77	17.0	22.06	45.17
Radiation and cooling losses	2.8	4.48	5.04	5.32	5.60
Reduction of metalloids	4.71	4.71	4.71	4.71	4.71
Reduction of FeO by carbon	...	13.20	19.62	19.62	19.62
Calcination of CaCO ₃	...	...	...	7.2	7.2
Evaporation of moisture	...	...	...	...	5.6
Reduction of Fe ₂ O ₃ by CO	...	...	...	...	0.8
Heat of formation of slag	...	-2.8	-2.8	-2.8	-2.8
Gaseous reduction of FeO	...	...	...	-1.84	-1.84
Total	9.06	32.36	43.57	54.27	84.06

Thermal balance of the iron blast-furnace

H. B. Bell and J. Taylor

THERMAL BALANCE DATA are most valuable to the student of the blast-furnace process, particularly at the present time in view of the current interest in blast additives. They provide a cross check on the validity of data. In addition, the carbon balance is a necessary step in the thermal balance calculation and from the carbon balance (a) the degree of gaseous reduction and (b) the volume of air blown are derived. The former (a) is the best basis on which to make comparisons of different burdens, and the latter (b) is a useful operational guide to the extent of air leakage. Few operators have any knowledge of the extent of this, which can vary from ~12% in good conditions to ~20% in poor.

The difficulties associated with the sampling and analysis of top gas have been the greatest barrier to the determination of thermal balances. These difficulties have been largely overcome and one would hope to see thermal balance data widely used and quoted. Although in principle the calculation is straightforward, it can also be rather tedious and complicated. With experience many simplifications can be introduced. The following simplified method is submitted as one which could well be carried out on a routine weekly or monthly basis by furnace operators.

There is considerable disagreement between different authors as to which side various items should appear. We have included on the heat-required side those fixed items such as reduction of oxides, sensible

SYNOPSIS

The value of thermal balance data to the student of blast-furnace technology is stressed. A simplified method of calculation suitable for routine operational control is given. From certain quoted examples it is suggested that agreement between input and output of $\pm 3\%$ ought to be achieved if data are reliable.

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heat of slag and metal, and cooling losses which are outside the immediate control of the operator. On the heat-supplied side are those items which vary with efficiency of operation: potential heat of coke, sensible heat air blast, top gas, etc. The one item which does not readily fit in to this scheme is decomposition of water. When steam additions are made to the blast, that is operational policy and it could then be argued that it should go on to the heat-supplied as a negative item.

The basic thermochemical data required have been given in the Appendix to a previous paper.¹ An expression is given for radiation and cooling losses based on thermal balance data determined in student exercises from this department. It is obviously preferable that the value should be obtained for the furnace in question. Since water cooling losses account for about 90% of the total the determination is straightforward and in our experience remains substantially constant for long periods of time.

Examples are given from data taken from the literature and private information. On this evidence it

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would appear that, at least for high sinter burdens, the error in the balance should normally be within $\pm 3\%$.

The data for Consett are taken from a period of five weeks in which the furnace operated very steadily and for which the data are reliable.

ACKNOWLEDGMENTS

The authors wish to thank the blast-furnace superintendent, Mr Ian Lockerbie, for making the data available and also the Consett Iron Company Ltd, for permission to use these data.

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APPENDIX

EXAMPLES OF THERMAL BALANCES

Heat supplied (basis 1 lb pig iron)

	Clyde ²	Kokura ³	Dom-narvet ⁴	Consett
Carbon used/lb { Ca	0.63	0.473	0.5075	...
Cu	0.589	0.425	0.4635	0.487
A , Btu	8420	6080	6640	6980
Carbon in top gas/lb Ct	0.601	0.425	0.4635	0.493
Top gas volume, ft ³	44.5	31.9	32.4	37.4
B , Btu	542	280	339	420
Air blown, ft ³	32.4	23.7	23.7	27.5
C , Btu	815	738	875	620
CO in top gas, ft ³	13.2	7.3	8.1	9.3
D , Btu	4350	2480	2750	3160
Heat supplied, Btu	4343	4058	4426	4020
Heat required, Btu				
E Reduction of oxides	2726	2768	2940	2760
F Heat content of pig iron	736	656	710	678
G Heat content of slag	366	336	370	284
H Calcination	52	Nil	Nil	37
J Moisture composition	71	83	104	84
K Radiation and cooling	191	190	200	160
L Evaporation of moisture	175	26	36	60
Heat required	4317	4059	4100	4063
Difference, %	0.6	0	5	1
FeO(D), %	52	37	53	42

INFORMATION REQUIRED FOR THERMAL BALANCE ON BLAST-FURNACE

All data to be on basis of 1 lb pig iron

- 1 Coke rate
- 2 Coke analysis: H₂O, carbon or ash, volatile matter, nitrogen (can assume 0.8% without much error), sulphur
- 3 Amount of blast additive, e.g. oil, coal, etc.
- 4 Analysis of additive: carbon, nitrogen, hydrogen, oxygen
- 5 Calcium charged carbonate
- 6 Magnesium charged carbonate
- 7 CO₂ charged as ironstone: only important if large
- 8 Carbon ejected in flue dust
- 9 Accurate top gas analysis: CO, CO₂, N₂, H₂, CH₄
- 10 Blast temperature and humidity
- 11 Top gas temperature
- 12 Iron charged as Fe₂O₃, FeO, and Fe
- 13 Pig analysis: C, Si, Mn, P
- 14 Slag weight: estimated slag weights are adequate since even an error of 1 cwt/ton means only 40 Btu
- 15 Radiation and cooling losses should be determined for furnace. An approximate value can be obtained using data below in section K, but actual determination for individual furnaces would make the balance much more reliable.

Note: In normal cases, i.e. where no additive such as oil or coal is used, terms marked with an asterisk * can be ignored.

THERMAL BALANCE

Heat supplied

Carbon used

COKE If no carbon analysis, % carbon = $100 - (0.97\% \text{ ash} + \frac{1}{3}\text{VM}\% + \text{N}\% + \text{S}\% + 1.5\%)$

Hence coke carbon = % carbon \times dry coke rate = Cu lb/lb pig

Coke carbon consumed = Cu - (C in pig + C in flue dust) = Ca lb/lb pig

ADDITIVE* % carbon in addition \times wt = Co lb/lb pig

Heat evolved in burning to CO₂

A { Coke carbon $\times 14300$ Btu/lb pig
Additive carbon* $\times \Delta H$ for fuel carbon (see below)

Carbon in top gas (CH₄ not included)

Ct = [Ca + Co* + 0.12 CaCO₃ + 0.137 MgCO₃ + 0.27 CO₂] lb/lb pig
(CO₂ = CO₃ in ore)

Gas analysis gives C_g = %CO₂ + %CO

N_g = %N₂ in top gas

Top gas vol. = $\frac{2990 \text{ Ct}}{C_g}$ ft³/lb pig iron

Sensible heat of this gas at top gas temp.

B = vol. $\times 0.038 \times \text{temp. } ^\circ\text{C}$ = Btu/lb pig

Air blown = $\frac{37.8 \times N_g \times \text{Ct}}{C_g}$ ft³/lb pig iron

Sensible heat of this air at blast temperature

C = vol. air $\times 0.0374 \times \text{temp. } ^\circ\text{C}$ = Btu/lb pig

CO in top gas = $\frac{\text{Top gas vol.}}{100} \times \% \text{CO}$ ft³/lb pig

D Potential heat of CO = volume $\times 340$ Btu

Heat supplied to furnace = (**A** + **C**) - (**B** + **D**) Btu/lb pig iron

Heat required

E Reduction of oxides

Iron from Fe₂O₃ $\times 3150$ Btu/lb pig

Iron from FeO $\times 2040$ Btu/lb pig

F Heat content of pig iron

At 1427°C = (%Fe $\times 4.5$) + (%Si $\times 131$) + (%Mn $\times 38$) + (%P $\times 96$)

+ (%C $\times 19$) Btu/lb pig

For each 10°C above 1427°C add 3.6 Btu

G Heat content of slag

765 \times slag weight Btu/lb pig at 1450°C

For each 10°C above 1450°C add 4.5 Btu

H Calcination of carbonates

CaCO₃ = 520 \times wt CaCO₃ Btu/lb pig

MgCO₃ = 550 \times wt MgCO₃ Btu/lb pig

This takes into account heat formation of slag

J Decomposition of moisture

Air volume \times humidity (gr/ft³) $\times 0.877$ Btu/lb pig

(If additive is used with hydrogen content see section M below)

K Radiation and cooling

These should be determined for furnace involved (if not available then use an approximate estimate from

$\frac{25300 \times \text{hearth dia.}}{\text{weekly output, tons}} \times 1.8$ Btu/lb pig iron)

L Evaporation of moisture

Moisture in burden vaporized and raised to top gas temp. = (wt moisture $\times 970$) + (wt $\times 0.8 \times \text{temp. } ^\circ\text{C}$) = Btu/lb pig iron

HYDROGEN BALANCE*

(This replaces section J when using additive with hydrogen content)

M Total hydrogen

Coke = $\frac{\text{coke wt} \times \% \text{H}_2}{100}$ lb/lb pig Hc

Blast moisture = $\frac{\text{air vol.} \times \text{humidity (gr/ft}^3\text{)}}{63000}$ lb/lb pig Hm

Additive = $\frac{\text{wt additive} \times \% \text{H}_2}{100}$ lb/lb pig Ha

(If data for hydrogen in coke are not available 0.5% can be taken as rough value)

Total hydrogen = Hc + Hm + Ha = H_t

Hydrogen in top gas = $\frac{\text{Top gas vol.} \times \% \text{H}_2}{18000}$ lb/lb pig = H_g

(H_t - H_g) = H₂ as H₂O in top gas

Hydrogen converted to water by oxide reduction = (H_t - H_g) - H_m

This may be positive or negative depending on conditions

Heat supplied or absorbed = (H_t - H_g) - H_m $\times 52000$ Btu/lb pig

If negative then absorbed, if positive then supplied.

Heat required = E + F + G + H + J (or M) + K + L Btu/lb pig iron

Calculation of amount of direct reduction

Carbon burned at tuyeres

$$= (\text{air vol.} \times 0.0140) + (\text{weight additive} \times \%O_2 \text{ in additive} \times 0.0075)$$

 $= C_b$ Hence $FeO_{(D)} =$

$$\frac{(Ca + Co) - [C_b + 0.002(\%Mn + 4.4\%P + 3.9\%Si)] - [Hm \times 6]}{(0.214 \times \%Fe)} \times 100\%$$

(Where proportion of scrap is charged only $\%Fe$ from oxide reduction used) $FeO_{(D)}$ is the percentage iron reduced directly by the reaction $FeO + C = Fe + CO$ **Heat of combustion of carbon in additive***

Oil carbon = 13 400 Btu/lb carbon

Coal carbon = 12 600 Btu/lb carbon

Anthracite carbon = 14 400 Btu/lb carbon

These figures are taken from typical examples of heavy oil, low-

grade coal, and anthracite. In the case of oil or anthracite, variations are not large but with coal they may be significant. The values can be obtained from the following equation:

Heat of combustion =

$$\frac{\text{Total heat of combustion} - \text{heat of combustion of hydrogen}}{\text{Fraction carbon in addition}}$$

$$= \frac{\text{Total heat of combustion} - (\text{fraction } H_2 \times 52\,000)}{\text{Fraction carbon in addition}}$$

Note: If blast is enriched with oxygen, section C should be altered.

$$\text{Air volume} = \frac{3000 \times N_2 \times Ct}{(100 - \%O_2) \times C_r}$$

where $\%O_2$ is that in the blast.

Carbon burned at tuyeres is then

$$\frac{\text{air volume} \times \%O_2}{1500} + (\text{wt additive} \times \%O_2 \text{ in additive} \times 0.0075).$$

Tensile properties of nitrogen-austenitized chromium steels

E. T. Turkdogan and S. Ignatowicz

INTRODUCTION

IT WAS FIRST noted by Adcock¹ that the Fe-Cr alloys could dissolve more nitrogen than the Fe-C alloys. Studies by Krivobok² and Franks³ showed that steels containing high percentages of chromium could be made austenitic by increasing the nitrogen concentration. Colbeck and Garner⁴ investigated the effect of nitrogen addition and heat treatment on the mechanical properties of high chromium steels. They found that improved toughness and ductility could be obtained by quenching steels containing 22–28%Cr and about 0.25%N, from 1100–1200°C. About 20 years ago attempts were made to use manganese in place of nickel in the manufacture of austenitic stainless steel. With this in view, some work was done on the effect of nitrogen on Cr-Mn steels.^{5–7}

From these early studies, it became clear that some of the austenite stabilizing elements of strategic importance could be replaced partly or wholly by small percentages of nitrogen without impairing the mechanical properties of austenitic steels. In recent years, more work has been reported on nitrogen-bearing Cr, Cr-Mn, and Cr-Mn-Mo steels.^{8–13} It was found that¹⁰ the alloy 16Cr–14Mn–2Mo–0.5N has properties similar to those of the commercial alloy 16Cr–25Mn–6Mo. It was shown that¹¹ the additions of carbon and nitrogen together could convert steels containing 21–33%Cr to the austenitic state at about 1200°C. The minimum concentration of $\%C + \%N$ required for a completely austenitic structure increases with increasing chromium content, and it was found that¹³ at about 1200°C

SYNOPSIS

A study has been made of the tensile properties of heat-treated Fe-Cr-N steels containing up to 30%Cr and up to 1.6%N. When quenched from 1100–1300°C, the tensile strengths of the alloys increase with increasing nitrogen content. The maximum beneficial effect of nitrogen increases with increasing chromium content. In alloys containing 25–30%Cr, percentage elongation and percentage reduction of area also increase with increasing nitrogen concentration. However, in nitrogenized 18–8 stainless steel ductility decreases with increasing nitrogen content. The toughness of these alloys is attributed to the retention of the austenite phase by quenching. The microscopical examination and the extraction of nitrides indicate that although nitrogen in the austenite phase is retained in solution by quenching from, say, 1200°C, most of the nitrogen in the ferrite phase comes out of solution as Cr_2N . A few microhardness measurements made indicate an increase in hardness with increasing nitrogen content. The effect of pressure on the solubility of nitrogen in Fe-Cr melts is shown and suggestions are made concerning the replacement of some of the nitrogen by carbon so that a high tensile-strength austenitic chromium steel may be produced under an atmospheric pressure of nitrogen.

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and 12.5%Cr, the minimum value of $\%C + \%N$ should be 0.078.

Recently the authors^{14,15} have measured the solubility of nitrogen in iron containing up to 30%Cr and evaluated the part of the ferrite/ferrite+austenite/austenite phase boundaries for a few temperatures and

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TABLE I Composition of the Fe-Cr alloys

Cast no.	Cr	N	C	Si	Mn	Ni	S	P	O
413	28.8	0.037	0.06	<0.01	0.01	0.01	0.020	<0.01	0.155
L751	26.2	0.070	0.05	0.34	0.34	0.24	0.017	0.022	...
L763	26.7	0.200	0.04	0.38	0.49	0.18	0.019	0.022	...
MAL2	18.7	0.050	0.09	0.17	0.25	7.7	0.024	0.018	...

concentrations of chromium and nitrogen. Following this work, some research was carried out on the tensile properties of nitrogen-bearing Fe-Cr alloys and the results obtained will be given in this paper.

EXPERIMENTAL

Preparation of alloys

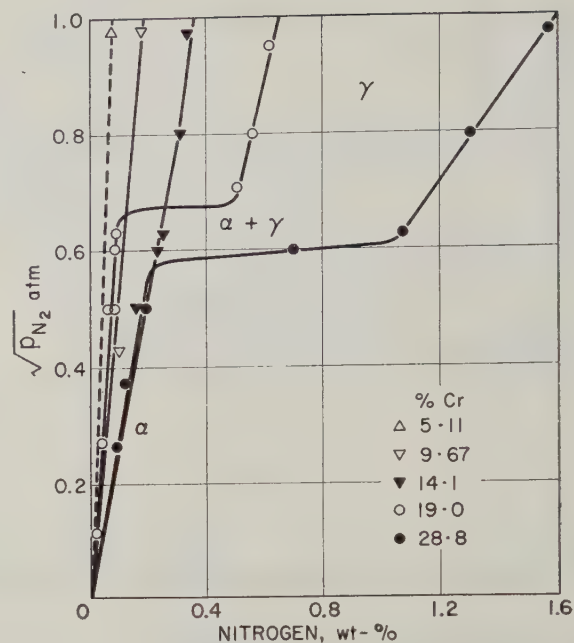
An alloy containing 28.8%Cr was made in BISRA laboratories using a vacuum melting unit. The 50 lb ingot was subsequently hot-forged, rolled, and finally cold drawn as a bar $\frac{1}{8}$ in dia. Two commercial chromium alloys and one 18-8 stainless steel were specially prepared by one of the steelmaking firms in Sheffield and these alloys were hot rolled to $\frac{3}{8}$ in dia., tempered at 750°C, and cold drawn to $\frac{9}{16}$ in dia. The compositions of the four alloys used in this work are given in Table I.

The tensile test specimens machined for the Hounsfield tensometer were 3.5 in long and 0.18 in dia. with a 2 in gauge length.

Nitrogenizing treatment

After machining, the tensile specimens were nitrogenized by first heating in anhydrous ammonia at 800°C, then sealed in evacuated silica capsules and homogenized at 1200°C for several days. Microscopical examinations indicated that during the first stage of nitriding in ammonia, a nitrogen-rich casing was formed. According to the X-ray diffraction pattern, this nitride phase was CrN. During the homogenizing treatment at 1200°C, the chromium nitride dissociated and nitrogen diffused into the bulk of the specimen producing a homogeneous ferrite, austenite, or a duplex ferrite+austenite structure. When a duplex structure was produced, the case of the specimen, about 0.05 in thick, was austenitic and the core had ferrite+austenite phases. A series of experiments was carried out to determine the time required to obtain even distribution of nitrogen through the specimen when it was completely in the austenitic state. For this purpose, a number of specimens of the alloy 413 (28.8%Cr) were nitrided in ammonia at 800°C for 6 h and homogenized, as described above, at 1200°C from 1 to 6 days and quenched in water. Their sections were then examined under a microscope and microhardness measurements were taken across the diameter of the sections, followed with the analysis for nitrogen of the samples taken from the different positions across this section. The results of all the measurements indicated that the minimum time required to reach uniformity was 2 to 3 days homogenizing treatment; in subsequent treatments, the tensile specimens were kept at 1200°C for 4 to 5 days. To obtain nitrogen concentrations above 1%, a double ammonia treatment was given (6 h each) with an intermediate and final homogenizing at 1200°C.

Experiments were also carried out to ascertain whether distribution of nitrogen along the axis of the

**1** Solubility of nitrogen in Fe-Cr alloys at 1200°C

specimen was uniform. This was checked by analysing for nitrogen the samples taken at 0.5 in intervals along the tensile specimens. Some of the specimens were also sectioned longitudinally and microhardness measurements were taken. The results clearly indicated that along the middle 2 in gauge length, the tensile specimens could be regarded as homogeneous within the limits of the experimental errors. The nitrogen contents of the ends of the specimens (outside the gauge length) were higher by about 0.1%, and correspondingly, the hardness of these parts was also higher than that within the gauge length.

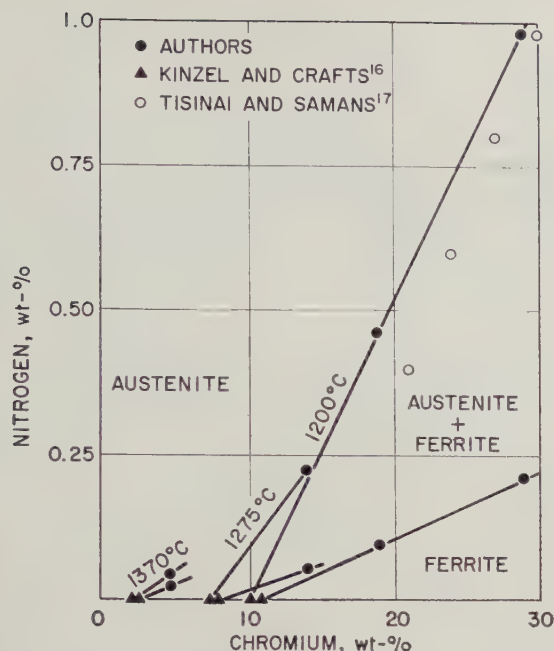
Heat treatment

After homogenizing treatment, the specimens were quenched in water. Still in their evacuated silica capsules, the specimens were reheated to 1100°, 1200°, or 1300°C for about 2 h and were quenched in iced brine solution, and to promote rapid quenching the silica capsules were broken manually at the time of quenching. If the samples were not to be tempered, they were tested within about 1 h of quenching; it might therefore be assumed that very little or no quench-ageing took place. Some of the specimens were tempered for 1 h in an atmosphere of argon at 150°, 300°, or 450°C and again quenched in iced brine solution.

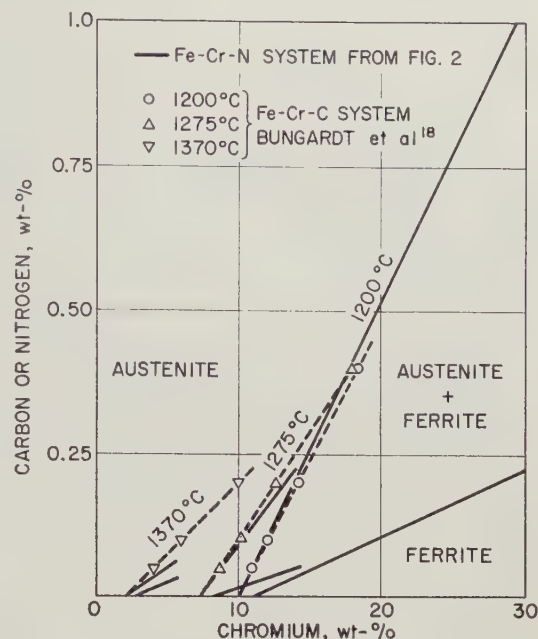
Nitrogen analysis and extraction of the nitride phase

The samples were analysed for nitrogen by the micro-Kjeldahl method. Although samples dissolved readily in hot 25% sulphuric acid solution, to insure complete dissociation of the nitride phase, the solution was boiled to fuming. The reproducibility of the analysis was within $\pm 1\%$ of the nitrogen content.

A number of samples were dissolved in bromine-methyl acetate solution and the insoluble matter was isolated and its X-ray diffraction pattern was obtained.



2 Part of the α - γ phase boundaries in Fe-Cr-N systems at 1200°, 1275°, and 1370°C



3 Comparison of α - γ phase boundaries in Fe-Cr-N and Fe-Cr-C alloys

DISCUSSION OF RESULTS

Ferrite-austenite phase boundaries

As already mentioned, the solubility of nitrogen in Fe-Cr alloys was measured by the authors.^{14,15} To facilitate the discussion of the present work, some consideration will now be given to the solubility data.

The solubility data for 1200°C are summarized diagrammatically in Fig.1. At 1200°C, the Fe-Cr-N alloys containing more than about 10%Cr could be in the ferritic or austenitic state, this being dependent on the nitrogen content. The discontinuities of the lines for the alloys containing 19.0% or 28.8%Cr give the conditions of transformation from ferrite to austenite phase. It should be pointed out that although Sievert's law is obeyed within the ferrite phase, there is a slight positive deviation from Sievert's law in the austenite range as observed from the extrapolation of the lines for the austenite phase to lower nitrogen partial pressures.

In Fig.2, the concentration of nitrogen is plotted against that of chromium for alloys where the phases ferrite/ferrite+austenite/austenite are in equilibrium at 1200°C. The lines drawn through the points for 19.0% and 28.8%Cr alloys agree well with those for the Fe-Cr binary system derived from the work of Kinzel and Crafts.¹⁶ Tisinai and Samans¹⁷ recently studied the phase relationships in the Fe-Cr-Ni-N alloys. Their values (extrapolated to zero nickel concentration) for the ferrite+austenite/austenite phase boundary lie below those obtained from the present work. This difference is believed to be due to the presence of 0.1-0.2%C in their alloys. In the presence of small percentages of carbon, the sum of carbon and nitrogen may be used in plotting these phase boundaries. Unfortunately, Tisinai and Samans have not analysed all their samples for carbon and therefore their values for this phase boundary could not be corrected. The points for 1275° and 1370°C are those determined previously by the authors.¹⁴

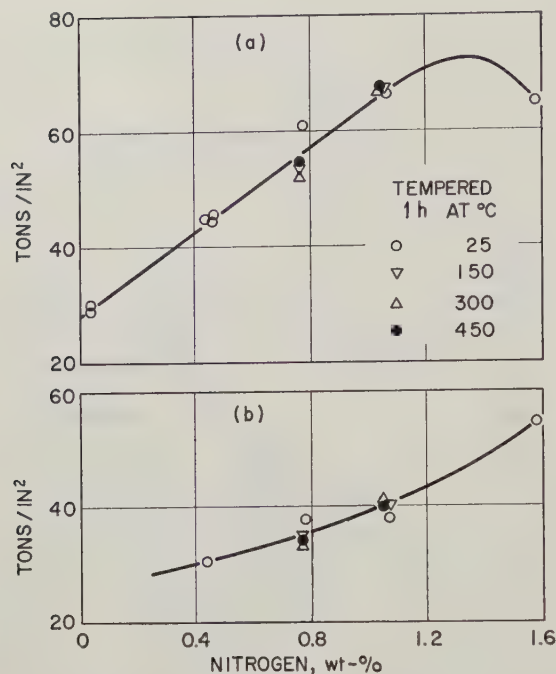
Recently, Bungardt, Kunze, and Horn¹⁸ studied in detail the phase equilibria in the Fe-Cr-C system. Using their diagrams, ferrite+austenite/austenite phase boundary for carbon-bearing Fe-Cr alloys is plotted in Fig.3 for three temperatures; the full lines, reproduced from Fig.2, are for the nitrogen-bearing alloys. The position of this phase boundary in these two ternary systems are very close to one another, indicating that the data given in Fig.3 may apply equally well to the quaternary Fe-Cr-N-C alloys. However, it should be borne in mind that, unlike nitrogen, carbon forms carbides in Fe-Cr alloys at much lower concentrations. For example, in an alloy containing 0.4%C and 20%Cr, the carbide Cr_{23}C_6 forms in the austenite+ferrite range at 1200°C. At the same temperature and 1%C concentration, Cr_7C_3 precipitates from the austenite phase when the chromium content is within the range 8-19%.

Although some work has been done¹¹ on the limits of the austenite phase in the Fe-Cr-N-C alloys, the data so far available are not sufficient to warrant any detailed discussion of the ferrite/austenite boundaries in the quaternary alloys.

Tensile properties

In Figs.4-6, maximum and proof stresses are plotted against the nitrogen content of three chromium alloys. The alloys were quenched in water from 1100°, 1200°, or 1300°C, and some of the alloys containing 28.8%Cr were tempered at various temperatures. The following are the characteristic features of these plots:

- 28.8%Cr alloy: tempering for 1 h at temperatures below 450°C has no effect on the tensile strength
- 26.7%Cr alloy, and 18-8 stainless steel: the quenching temperature within the range 1100-1300°C does not affect the tensile strength
- the tensile strength increases appreciably with the nitrogen content of the alloy, but at high

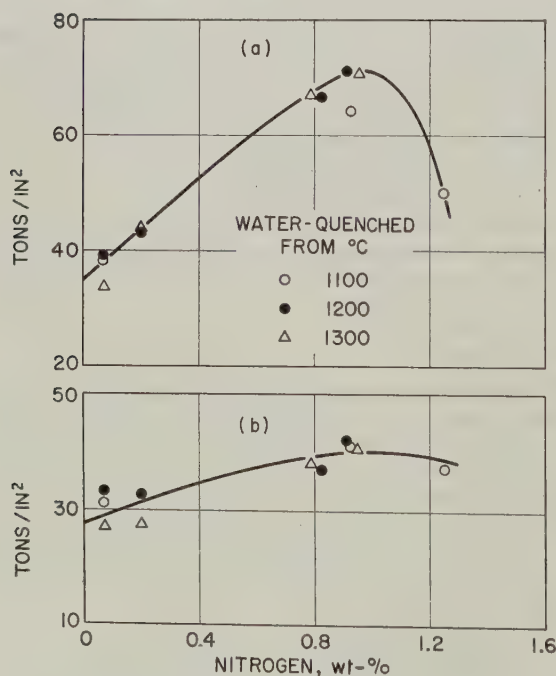


a Maximum stress, b proof stress at 0.25% strain

4 Tensile properties of Fe-28.8%Cr-N alloys, water-quenched from 1200°C

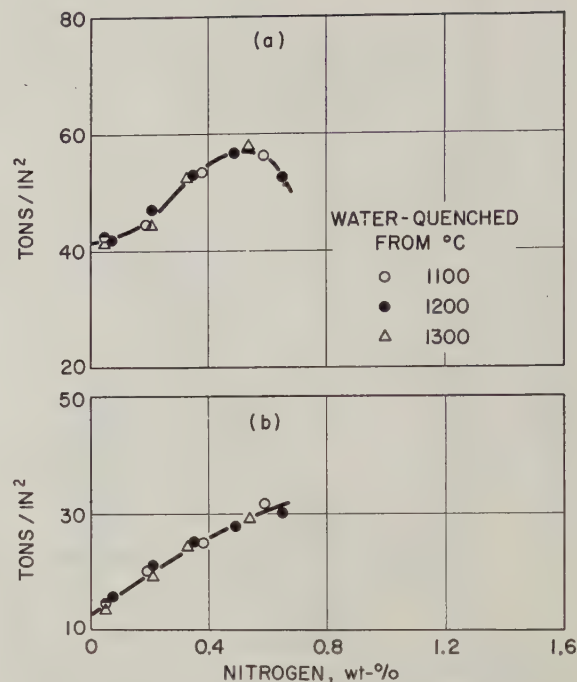
nitrogen concentrations the maximum strength decreases. The nitrogen content, at which maximum tensile strength is reached, decreases with decreasing chromium content of the alloy

(iv) two points in Fig.5a, at 0.2%N, were obtained from the alloy which originally contained 0.2%N, i.e. no nitrogenizing treatment was



a Maximum stress, b proof stress at 0.25% strain

5 Tensile properties of Fe-26.7%Cr-N alloys, water-quenched from 1100°, 1200°, or 1300°C



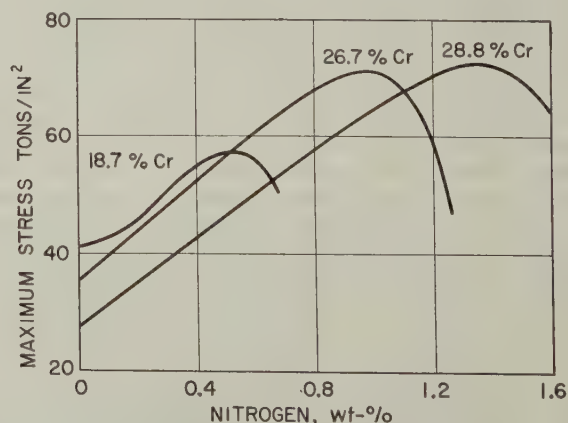
a Maximum stress, b proof stress at 0.25% strain

6 Tensile properties of 18-8N stainless steel, water-quenched from 1100°, 1200°, or 1300°C

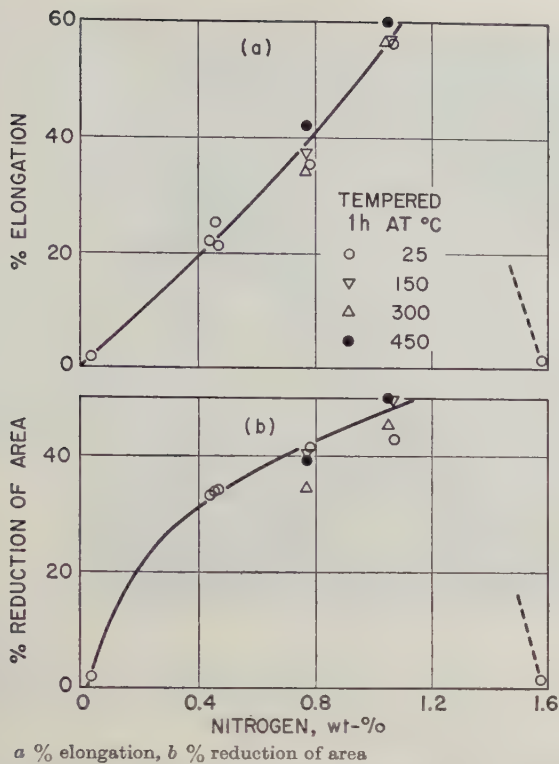
given, and its tensile strength appears to be concordant with those which were nitrogenized as described earlier. As long as the alloy has been subjected to the correct heat treatment, the manner in which the nitrogen is introduced into the sample should not make much difference to the ultimate tensile properties of the alloys

(v) in all the three alloys, the proof stress, at 0.25% strain, increases with increasing nitrogen content.

The tensile strengths of these three alloys are compared in Fig.7; the curves are positioned in a certain order relative to one another and it is quite conclusive that (i) to obtain the same maximum stress, nitrogen in the alloy must be increased with increasing chromium concentrations, and (ii) for a given nitrogen



7 Variation of tensile strength with nitrogen and chromium contents of alloys, water-quenched from 1200°C



8 Tensile properties of Fe-28.8%Cr-N alloys, water-quenched from 1200°C

content below 0.4%N, the maximum stress increases with decreasing chromium content.

The percentage elongation and percentage reduction of area for these three alloys are plotted in Figs. 8-10. In alloys containing 28.8% and 26.7%Cr, elongation and reduction of area during tensile testing increase with increasing nitrogen content, but further increase in nitrogen content results in brittleness. In 18-8 stainless steel, however, there is a continuous reduction of ductility with increasing nitrogen content. This observation requires a more detailed study before any satisfactory explanation can be offered.

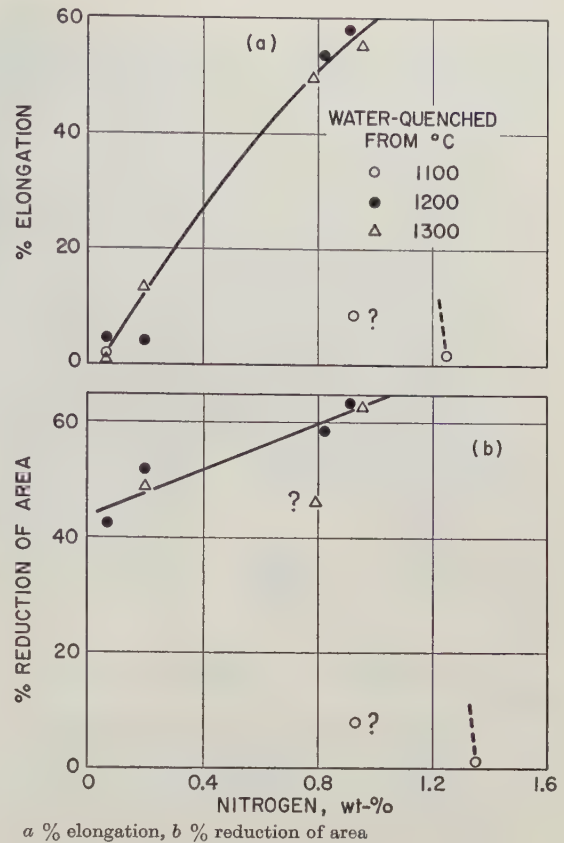
The comparison of the plots in Fig. 7 with those in Figs. 8 and 9 reveal that alloys containing 25% to 30%Cr and 0.8% to 1.4%N have high tensile strengths and high ductilities, indicating that these alloys could have some potential applications in practice.

Microscopical examination

Some of the alloys were examined under a microscope and the results are illustrated in the following photomicrographs. In all cases, the specimens for microscopical examinations were taken from the tensile test-pieces (within the gauge length) after tensile testing, and then the heat treatment was repeated as before.

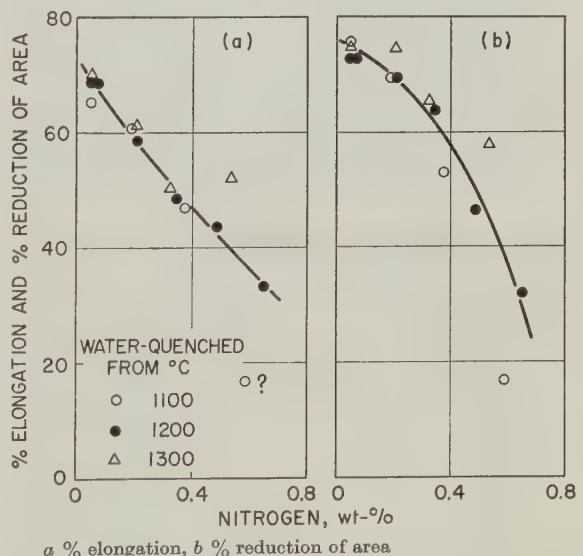
28.8%Cr alloys

Figure 11 shows the ferrite and austenite phases when 0.45%N alloy is quenched from 1200°C; the ferrite grains contain a precipitated phase. Figure 12, 0.78%N alloy, has a duplex structure similar to that in Fig. 11. This photomicrograph shows the core of the specimen; at this nitrogen level, the casing was found to be completely austenitic. Figure 13, 1.06%N alloy, shows (a) large austenite grains when quenched from 1200°C

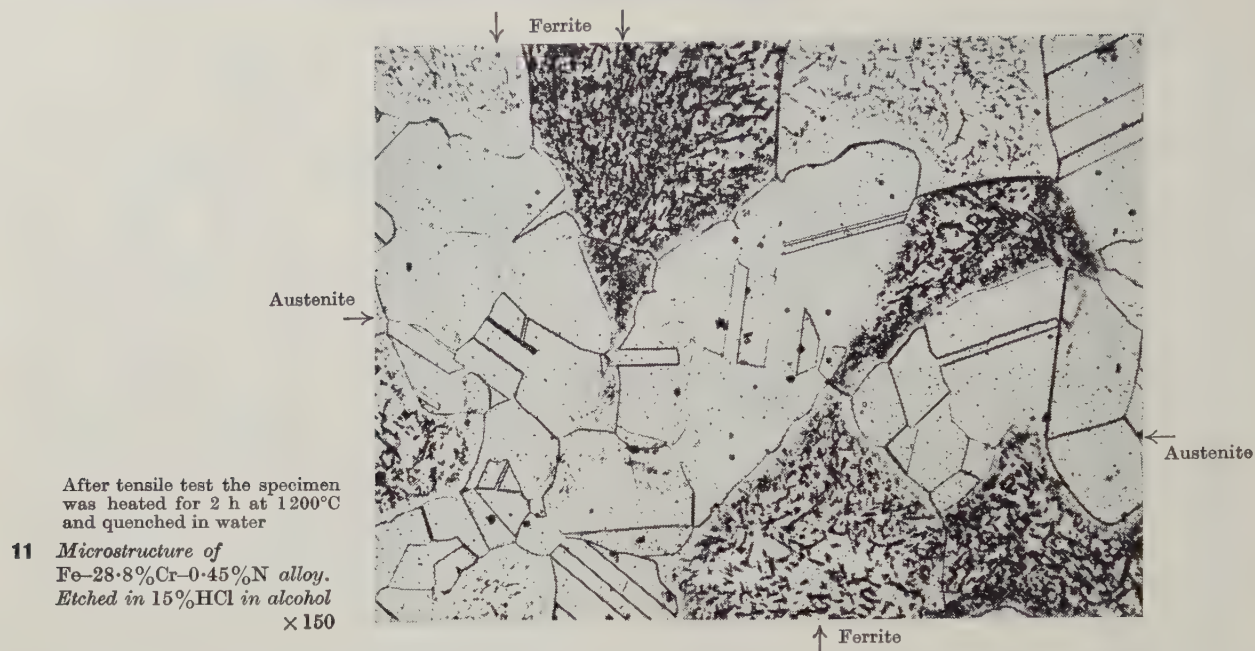


9 Tensile properties of Fe-26.7%Cr-N alloys, water-quenched from 1100°, 1200°, and 1300°C

and (b) the strain-lines occurring during plastic deformation in the tensometer. Figure 14, 1.58%N alloy, shows a heavy precipitate of a nitride phase in the form of round and elongated beads, the background being the austenite phase. The brittleness of this alloy as shown in Fig. 8 is evidently due to the presence of this heavy nitride precipitate.



10 Tensile properties of 18-8 stainless steel, water-quenched from 1100°, 1200°, or 1300°C



The following are the characteristic structural features:

- (i) the austenite phase reveals 'annealing twins' which become more pronounced with increasing percentage of the austenite phase in the structure. The formation of these twins is due to the history of the heat treatment given to the specimens, that is, any twins formed during the plastic deformation become the nuclei for the twin crystals which grow during heating to 1100–1300°C. The formation of the annealing twins by the above mechanism is a common occurrence in face-centred-cubic crystals
- (ii) while the ferrite/austenite grain boundaries are curved, the austenite/austenite grain boundaries are linear. The curvature of the ferrite/austenite grain boundaries may be attributed to the difference between the free surface energies of the two phases
- (iii) the microsections reveal numerous black spots increasing in number as the nitrogen concentration increases. At a higher magnification under microscope, these spots appear to be holes
- (iv) on quenching from 1200°C, the nitrogen is retained in the austenite phase at room temperature when the alloy contains up to about 1.1%N. At 1.6%N concentration, some of the

nitrogen comes out of solution but the matrix is still in the austenitic state as confirmed by its non-magnetic property.

26.7%Cr alloys

Figure 15 shows (a) large grains of ferrite in steel containing 0.07%N and (b) large grains of ferrite plus small rounded grains of austenite in steel containing 0.20%N. In both cases, nitrogen was introduced into steel when it was molten. Both structures reveal feathery precipitates, some of which are located parallel to the grain boundaries in Fig. 15a.

The structure in Fig. 16 for the alloy containing 0.82%N is mainly austenitic with small islands of the ferrite phase where some nitride precipitation has occurred. As indicated by the plots in Figs. 2 and 3, this alloy containing 0.85%N (+about 0.05%C) is on the borderline between the austenite/ferrite + austenite phases. The presence of 0.38%Si appears to have shifted this boundary towards the higher nitrogen level, as indicated by the microsection in Fig. 16.

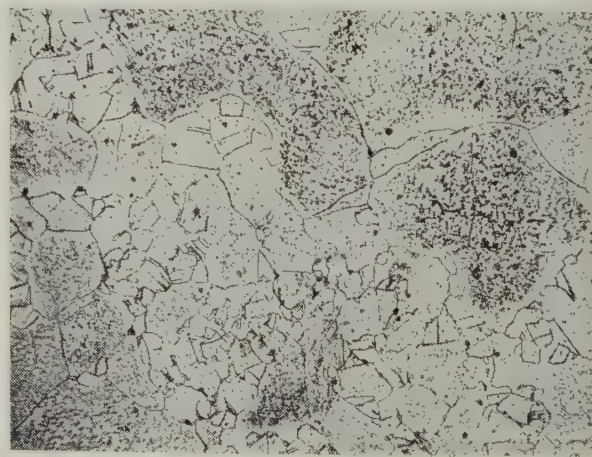
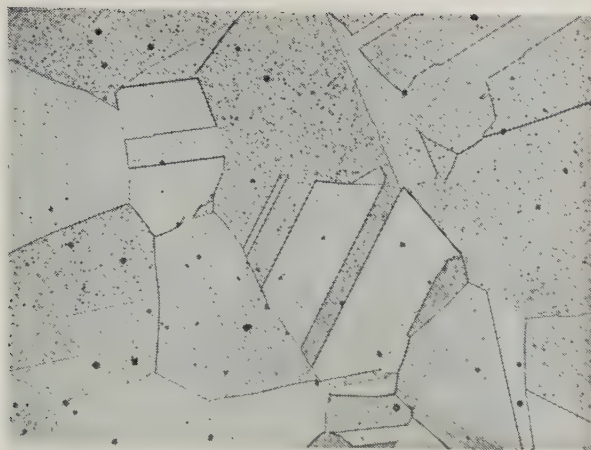


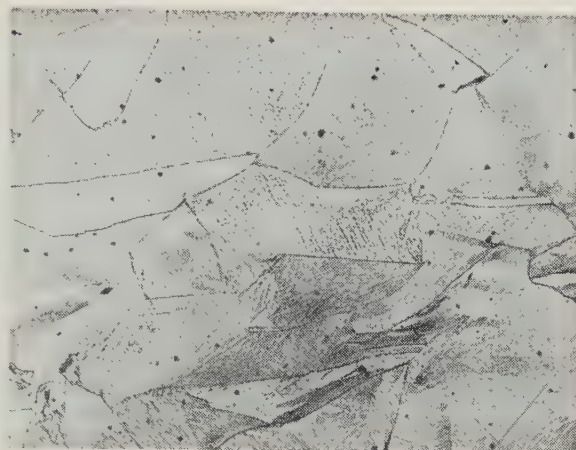
TABLE II Extracted insoluble matter

Sample	Alloy composition, wt.-%		Extract Cr_2N_3 , wt.-%*	Heat treatment
	Cr	N		
A	28.8	0.78	0.5	WQ from 1200°C
B	28.8	1.06	0.1	WQ from 1200°C
C	28.8	0.78	3.1	WQ from 1100°C
D	28.8	0.78	5.4	Slowly cooled from 1200°C
E	28.8	1.58	7.8	WQ from 1200°C
F	26.7	0.82	0.09	WQ from 1200°C
G	26.7	0.92	0.08	WQ from 1200°C
H	26.7	1.25	9.44	WQ from 1200°C
I	18.7	0.05	0.06	WQ from 1200°C
J	18.7	0.49	0.05	WQ from 1200°C
K	18.7	0.65	0.18	WQ from 1200°C

* Containing some Cr_2O_3 .



a After tensile test the specimen was heated for 2 h at 1200°C and quenched in water



b Water-quenched from 1200°C and broken in the tensometer

13 Microstructures of Fe-28.8%Cr-1.06%N alloy. Etched in 15% HCl in alcohol

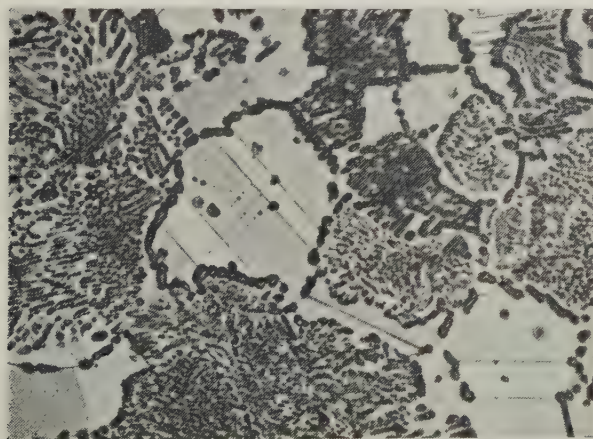
× 150

The alloy containing 0.92%N is completely austenitic as shown in Fig.17 and as indicated by its non-magnetic property.

The characteristic features of the microsections of this alloy are very similar to those mentioned above (i-iv) for the alloy containing 28.8%Cr.

18-8 stainless steel

The microsections of the heat treated 18-8 stainless steel containing 0.07% to 0.65%N are given in Figs.18 and 19; showing large austenite grains with annealing twins, and similar to the other alloys, the number and the average size of the blow-holes increase with increasing nitrogen content.



After tensile test the specimen was heated for 2 h at 1200°C and quenched in water

14 Microstructure of Fe-28.8%Cr-1.58%N alloy. Etched in 15% HCl in alcohol

× 150

No satisfactory explanation can be given, at present, to account for the appearance of blow-holes after the heat treatment of these nitrogen-bearing chromium-steels. Since the homogenizing and final heat treatment was made after sealing the samples in evacuated silica capsules, the amount of nitrogen likely to be lost from the specimen would be negligible. However, the evidence points to the fact that the presence of these blow-holes has some connexion with the nitrogen dissolved in the steel.

Extraction of the precipitated nitride

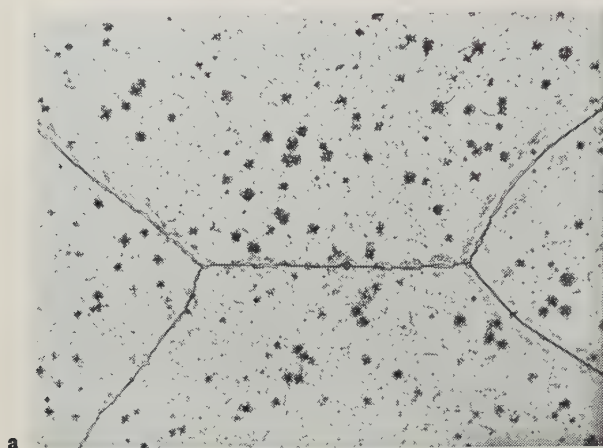
Table II gives the results of extraction of the nitrides precipitated during heat treatment. The studies indicated that, in all cases, the insoluble matter was identified as Cr_2N with a small amount of Cr_2O_3 . These results are concordant with the microstructures and tensile properties of these alloys. For example, sample A containing some precipitate in the ferrite phase of its duplex structure (see Fig.12) contains slightly more Cr_2N than sample B which is completely austenitic with only a trace of precipitate (see Fig.13a). When the alloy containing 0.78%N is quenched from 1100°C, or cooled slowly in the furnace from 1200°C, there was a heavy precipitation of Cr_2N . On tensile testing, these alloys (C and D) were found to be very brittle. It should be pointed out here that, as shown by the tensile strengths in Figs.5 and 6, quenching of the other two alloys from 1100°C did not cause brittleness, presumably owing to their lower chromium concentrations.

In 26.7%Cr alloy the highest tensile strength was obtained at 0.8-0.9%N concentration which was retained almost completely in solid solution as observed from the microsections and from the

TABLE III Typical mechanical properties of some austenitic steels*

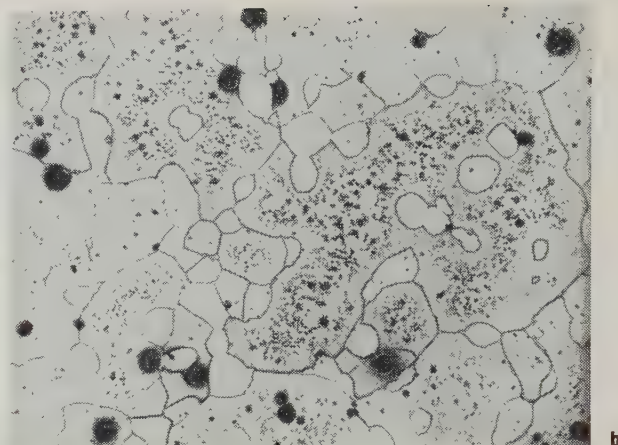
Type	Treatment	Composition range, wt.-%			Cr	Ni	Tensile, tons/in ²	YP, tons/in ²	Elong., %	Red., %	Hardness, DPN
Stainless steel		0.08-0.20	2.0	...	17-19	8-10	36-40	16-20	55-60	55-65	135-185
	Annealed						45-80	22-67	10-50	...	190-340
	Cold rolled						58-63	22-27	40-60	35-50	170-200
Mn steel	Cold rolled	1.1-1.4	11-14	0.2-0.6	...	...			
Ni-Mn steel	Cold rolled	1.1-1.4	10-14	0.2-0.6	...	3.3-3.8					
	WQ from 1040°C						59-69	22-28	48-72	40-60	165-195
							61	...	63	43	157

* ASM Metals Handbook, 1948.



a 0.07%N ferritic structure

After tensile test the specimen was heated for 2 h at 1200°C and quenched in water



b 0.20%N ferrite/austenite duplex structure

15 Microstructures of Fe-26.7%Cr-N alloys. Etched in 15%HCl in alcohol

× 150

amount of the precipitated phase extracted, e.g. samples *F* and *G* in Table II. The heavy precipitation of the nitride phase in sample *H* accounts for its brittleness as shown by the tensile properties in Figs. 5 and 9. Similarly, in 18-8 stainless steel maximum stress decreases when %N > 0.5, and in fact, the amount of the precipitated phase also increases at high nitrogen concentrations, e.g. sample *K* in Table II.

Microhardness measurements

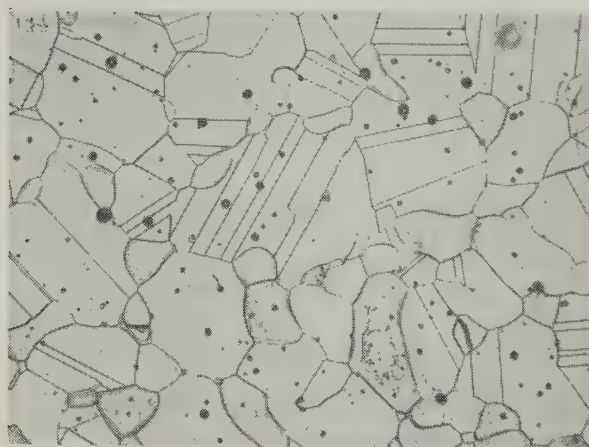
A few microhardness measurements were taken on some of the 28.8%Cr alloy containing 0.78% and 0.06%N, and the results are shown in Fig. 20. Although the data are sparse, the indications are that the hardness of the austenite phase is higher than that of the ferrite phase by about 120 VDH, at a nitrogen content of about 0.8%.

General considerations

The alloys studied contained less than 0.1%C and the nitrogen was the main interstitial element giving strength to the iron-chromium alloys; this strength

and high ductility are brought about by retaining the austenite phase by quenching. As seen from the results of Tisnai and Samans,¹² carbon and nitrogen, as would be expected, have similar effects on the tensile properties of chromium steels. As a first approximation, therefore, the combined effects of these two interstitial elements may be shown on the composition-diagram by using the sum of their concentrations. In this connexion, reference may be made to a paper by Hsiao and Dulis¹⁹ who showed that the yield strength of Fe-12%Cr10%(or 28%) Mn steels increased linearly with the sum of the concentrations %C + 1.2(%N). Similarly, the lattice parameter of these austenitic alloys increases linearly with %C + 1.2(%N).

From the practical point of view, the solution of nitrogen in chromium-steels by the solid-gas reaction, as described in this paper, can be applied within a reasonable reaction time, only for small sections. In the manufacture of larger sections, however, the nitrogen has to be introduced when the steel is in the molten state. With this in view, some considerations will be given to the solubility of nitrogen in molten Fe-Cr alloys. The solubility of nitrogen (at 1 atm pressure) in



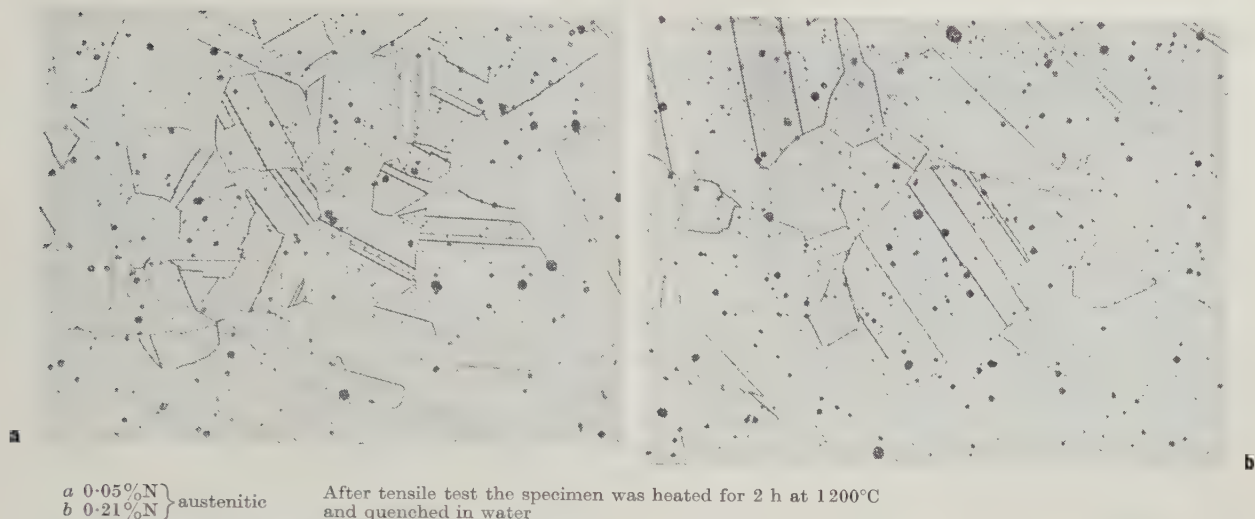
After tensile test the specimen was heated for 2 h at 1200°C and quenched in water

16 Microstructure of Fe-26.7%Cr-0.82%N alloy mostly austenite with little ferrite. Etched in 15%HCl in alcohol × 200



After tensile test the specimen was heated for 2 h at 1200°C and quenched in water

17 Microstructure of Fe-26.7%Cr-0.92%N alloy completely austenitic. Etched in 15%HCl in alcohol × 200



18 Microstructures of 18-8N stainless steel. Etched in 15% HCl in alcohol

× 150

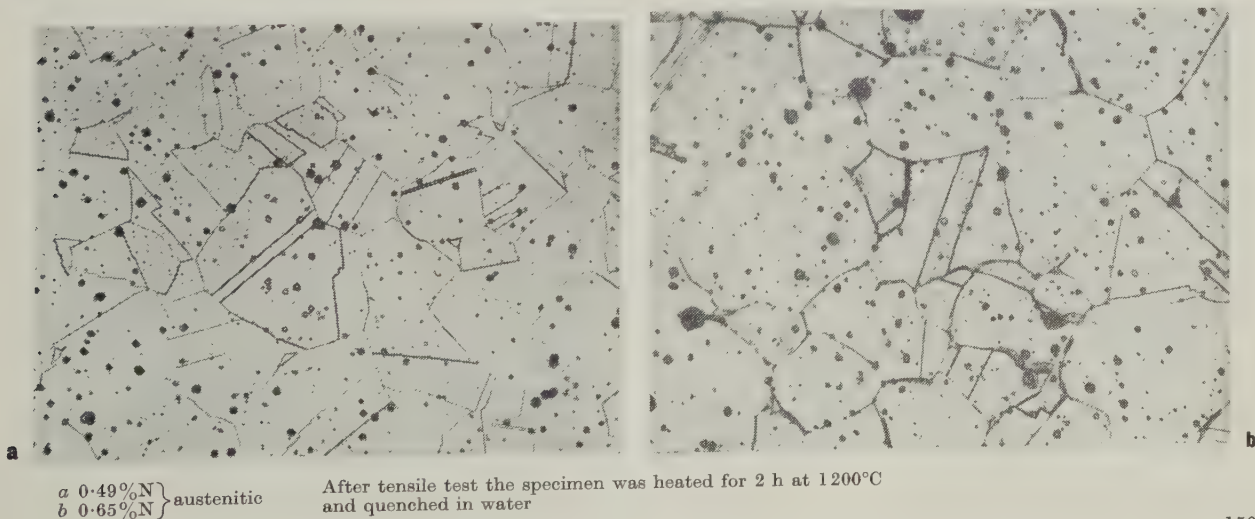
Fe-Cr melts was measured by Saito²⁰; on the assumption that solubility data can be extrapolated to higher pressures, the curves (for 1600°C) in Fig. 21 may be drawn for pressures up to 5 atm; the dotted lines A-B and C-D are for the α - γ phase boundaries for 1200°C. Although carbon lowers the solubility of nitrogen in molten iron²¹ at concentrations of about 0.2-0.4%, this effect is negligible. If an alloy containing 0.2%N is required, as indicated by the curves in Fig. 21, the melt should be made under a pressure of about 5 atm when the chromium content is 8%; on the other hand, the same nitrogen can be held in the melt at atmospheric pressure when the chromium content is increased to 16-17%. Since carbon and nitrogen have similar effects on the tensile properties of the Fe-Cr alloys, part of the nitrogen can be replaced by carbon, and in this way the production of the nitrogen-bearing alloy becomes somewhat simplified. For example, if an austenitic 20%Cr alloy is required to have a tensile strength of about 60 tons/in² after quenching from 1200°C, the sum of concentrations of carbon and nitrogen should be about 0.55%. If this alloy is to be melted under 1 atm pressure of nitrogen, then the alloy must contain about 0.25%C. In the absence of carbon, however, the pressure over the melt

should be increased to about 5 atm to allow the retention of 0.55%N in iron containing 20%Cr. Due consideration should, of course, be given to the upper limit of carbon concentration, otherwise the precipitation of the chromium carbides will impair the mechanical properties.

In Table III, a few data are given on the typical mechanical properties of some austenitic steels. The tensile properties of nitrogen-austenitized chromium steels given in this paper compare favourably with those of the more conventional austenitic steels. However, further work should be carried out on the Fe-Cr-N austenitic steels to explore the effect of nitrogen and method of heat treatment on other mechanical properties of these alloys.

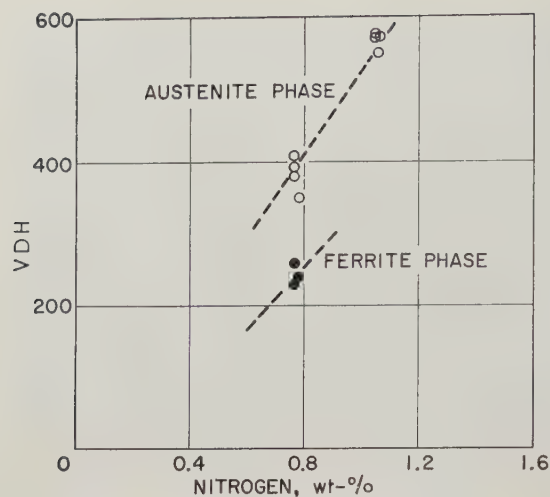
CONCLUSIONS

The tensile and proof strengths of Fe-Cr-N alloys increase with increasing nitrogen in solid solution; further increase of nitrogen reduces the tensile strength. When quenched from 1200°C, almost all the nitrogen is retained in solid solution in the austenite phase, but most of the nitrogen in the ferrite phase comes out of solution as Cr₂N.



19 Microstructures of 18-8N stainless steel. Etched in 15% HCl in alcohol

× 150



20 Microhardness (VDH) of Fe-28.8%Cr-N alloys quenched in water from 1200°C

The alloys containing 18.7% or 26.7%Cr and up to 0.6% or 1.25%N, respectively, have similar tensile properties when quenched from 1100–1300°C in water. At higher chromium concentration, however, quenching temperature is more critical, e.g. quenching from 1100°C results in nitride precipitation, but when quenched from 1200°C, nitrogen remains in solution in 28.8%Cr steel.

The tempering at temperatures up to 450°C does not have a noticeable effect on the tensile properties measured.

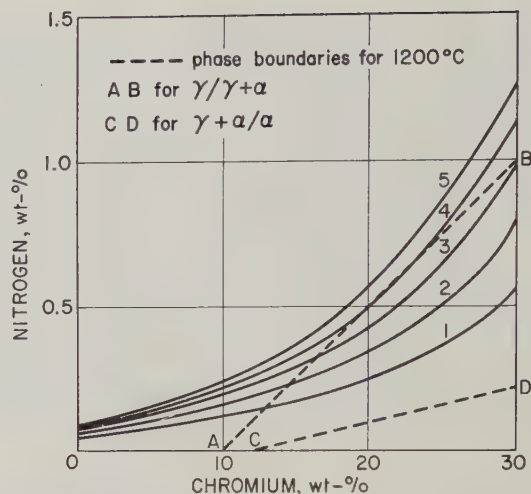
The hardness of heat treated 28.8%Cr alloy increases with the nitrogen content; the austenite phase has a greater hardness than the ferrite phase.

If, after quenching from 1100–1300°C, the specimen is cold worked, e.g. by pulling in the tensile machine, and then reheated and quenched, annealing twins appear in the austenite phase.

In alloys containing 26.7% or 28.8%Cr, percentage elongation and percentage reduction of area increase with increasing nitrogen content, reaching a maximum above which the steels become brittle. This maximum nitrogen content increases with increasing chromium concentration. On the other hand, in the 18–8 stainless steel the ductility decreases with increasing nitrogen content. Although the alloys were nitrogenized in the solid state, the microscopic porosity appears to increase with the nitrogen content; further work must be carried out to elucidate this observation.

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Joint meeting in Sheffield, April 1961

A joint meeting of The Iron and Steel Institute, the Sheffield Metallurgical Association, and the Sheffield Society of Engineers and Metallurgists was held in the Engineers Lecture Theatre, University of Sheffield on Wednesday, 12 April 1961. Mr F. H. Saniter, Vice-President of The Iron and Steel Institute and President of the Sheffield Society of Engineers and Metallurgists, was in the Chair. Four papers were presented and discussed during the sessions of the Meeting. The papers have already been published in the Journal. The discussions are given below.

Discussion on austenitic stainless steels

The discussion was based on the following papers. Dates of publication in the *Journal* are given in parentheses.

'The effect of heat-treatment and microstructure on the high-temperature ductility of 18%Cr-12%Ni-1%Nb steels', by K. J. Irvine, J. D. Murray, and F. B. Pickering, United Steel Companies Ltd (1960, **196**, 166-179)

'Some ductility aspects of 18-12-1Nb steel', by R. J. Truman and H. W. Kirkby, Brown-Firth Research Laboratories (1960, **196**, 180-188)

'Heat-affected zone cracking in welded high-temperature austenitic steels', by R. N. Younger and R. G. Baker, British Welding Research Association (1960, **196**, 188-194)

'Microstructural causes of heat-affected zone cracking in heavy section 18-12-Nb austenitic stainless steel welded joints', by N. E. Moore and J. A. Griffiths, Associated Electrical Industries (Manchester) Ltd (1961, **197**, 29-39).

Messrs Murray, Truman, Younger, and Moore presented the papers.

Mr H. F. Tremlett (British Welding Research Association): These papers are such that we can agree that strain-induced precipitation can occur in these steels in suitable circumstances and that time, temperature, and probably also the amount of strain are involved. The wrought steel specimens will show ductility troughs and peaks, and the steel metallurgist can happily discuss these and point to dangerous temperatures, e.g. at 850°C, but the welded joint has to go through the full temperature cycle and is stressed as soon as it has cooled down. It was not possible to talk about a ductility trough on a welded joint. That was the first point which required emphasis, to put the position into perspective from the point of view of the fabricator. It meant that, given the required degree of strain, there was not much that could be done in a weld joint to avoid critical temperature regions and heating periods.

The placing of a weld run on the steel was, metallurgically, a solution treatment of the parent steel at very high temperatures; the authors, I think, are mistaken in assuming that, on cooling down from the solution temperature, strain-induced precipitation occurs. At the BWRA we have examined a number of metal arc welded joints immediately after welding. No sign of strain-induced precipitation was found and I do not think that it is to be expected. The single-run weld is a solution treatment; times are extremely short and there is probably no opportunity for this precipitation to occur. In a rigid welded joint the processes of strain and precipitation are concomitant, as emphasized by Younger, if the joint cools out to room temperature and is re-heated. One could therefore expect

cracking up to temperatures at which carbide can be precipitated and this, according to recent information, is in fact what happens; cracking has been found to occur after re-heating at 850° and 950°C, two recent results not given in Table II of Younger's paper. Cracking did not occur on heating at 1050°C. To avoid ambiguity in interpretation, heating rates up to these temperatures had to be extremely fast, so that the critical time at 750°C was not reached during heating.

Irvine *et al.* have suggested that prior ageing treatment at 900°C should prevent this strain-induced precipitation. This can be applied to a welded joint in practice by pre-heating the joint to about 850°C and maintaining a temperature of around 900°C during welding. Younger has done this and has maintained a temperature of about 850°C for about 1 h before allowing the joint to cool down; there has been no sign of cracking and the carbides are present in the coarse form, which one would expect from the paper by Irvine *et al.* Whether or not that is a practical approach I do not know; there may be special deslagging difficulties in welding joints pre-heated to this temperature.

Regarding composition, the papers deal mainly with niobium-stabilized steels and there is a slight danger that this element will get itself a bad name. To put the position in perspective it may be helpful to show the results which Younger has obtained using this welding test on different steels, heating for 100 h at 750°C. Table 1 shows the change in crack susceptibility using four electrodes, A, B, C, and D which are in order of increasing hot strength and of increasing strain in the heat-affected zone. The results suggest that niobium can be present in steels which cover a wide crack susceptibility range, from cracking with all four electrodes to cracking with only the two electrodes producing the greatest strain conditions. Contrariwise, although the simple molybdenum steel does not crack with any electrode tested, molybdenum is present in a steel

TABLE 1 Relative crack susceptibility of various commercial steels treated 100 h at 750°C (BWRA weld test: hot tears not ground out)

	16 10 Mo	18 8 LC	18 8 Mo Nb Co	17 18 Ti	18 10 Nb Mo	16 12 6Mn Mo Nb B	18 12 Nb
A	...	Nil	...	Nil	Nil	Nil	Cr
B	Nil	Nil	Nil	Nil	Cr	Cr	Cr
C	...	Cr	Cr	Cr	Cr	Cr	Cr
D	Nil	Cr	Cr	Cr	Cr	Cr	Cr

A=Armex GT B=Nirex CC C=326 F D=Stellite 6

which cracks with three electrodes. The situation is, therefore, quite complicated and I think that, until more is known about the factors controlling strain-induced precipitation in austenitic steels, the only reliable guide to steel behaviour is weld joint testing under controlled and standardized conditions.

Mr J. D. Murray, in reply: Mr Tremlett began by saying that there was a difference between a welded joint and carefully prepared heat-treated sample. I should like to add that it is extremely dangerous to generalize about welded joints and in particular to say that NbC cannot precipitate during welding. In our paper we said that in actual welding using a Nb-bearing electrode, precipitation has occurred. We have identified this precipitate under the electron microscope. We have also seen a precipitate of NbC that is formed in the weld metal in the argon arc welding of thin sheet material. Precipitation, therefore, can occur on welding, given the right conditions of heating, cooling, and degree of restraint.

In our paper we make the comment that there is evidence from tensile and bend tests that low ductility in the 18-12-Nb steel can be removed by an ageing treatment at 900-950°C. In a welded joint which has not cracked during welding we believe that a high-temperature treatment can restore ductility provided that in the course of heating up for that purpose, cracking does not occur. The CEBG have confirmed this on actual components and perhaps Mr Mitchell will let us know more about this. The whole question of ductility in the 18-12-Nb steel revolves around a set of critical circumstances. There is a critical combination of strain, time, and temperature, and as yet we do not know how critical each one is. I agree with Mr Tremlett that it would be a very interesting exercise to make welds in 18-12-Nb steel with a pre-heating of 800°C. I hope that he has the courage to do it.

Mr B. Mitchell (Central Electricity Generating Board): The austenitic 18%Cr-12%Ni-1%Nb steel has been in service in CEBG power stations operating with steam at 1500 lb/in² and 565°C (1050°F) for about six years in the form of superheater tubes, headers, and steam piping. Very few failures or defects have occurred in superheater tubes, or steam piping with wall thicknesses less than about $\frac{1}{8}$ in. In heavier section components, however, extensive cracking has been experienced. The cracks were all of similar type, originating at, or close to, the fusion zone and propagating into the parent metal.

The fabrication procedures employed on these components was very varied. Some were put into service in the as-welded state with no post weld heat-treatment or dressing of the joints to remove hot tears or mechanical notches, while others were stress relieved at temperatures between 750° and 800°C and very carefully dressed and non-destructively examined.

Cracking has been widespread with all fabrication techniques, some of it being discovered after being in service from 24 to 20000 h and in certain cases before the components had been put into service, but after stress relieving.

A few years ago the incidence of cracking assumed serious proportions and the CEBG were compelled to consider either replacement or major factory repairs of superheater headers. The long delivery of replacements forced the CEBG to undertake the latter alternative. In collaboration with contractors, steelmakers, and insurance companies concerned with the components, a repair procedure was evolved which embodied all the precautions which could be envisaged at that time. This involved removal of all attachments, excavation of all weld metal, careful control of welding operations, dressing of all welds to remove hot tears and sharp notches, and stress relieving at 1050°C. On the basis of experience of cracks being initiated at 565°C in service and at 750° and 800°C during stress relieving it was decided to heat through this range as quickly as the furnaces would permit. Further, since the headers were of complex geometry and had to be re-fitted into an existing installation, distortion had to be minimized, and the headers were furnace cooled from 1050°C.

Sixty-four headers, containing upwards of 2000 welded joints, have been repaired in this way and no defects were

found after heat-treatment. Some of these headers have been in service for up to 20000 h and at the last inspection, after 12000 h no cracks were found.

These results are encouraging and it is gratifying to note that the findings reported in the papers being discussed today tend to support the decisions made by the CEBG some years ago.

Now that we have all the information which the authors have given, we see that 1050°C may not be the ideal, but what is important is that in heat-treating these components at 850°C there is a big difference in the short-term proof stress figures of the parent metal, the weld metal, and the heat-affected zone, and the latter has the lowest value. Consequently the strain due to relaxation of the stresses will be concentrated into this zone of low ductility. At 1050°C the proof stress values of these three zones are similar, so that the strains to relax these stresses are spread over a much wider area.

I wish to raise a question relating mainly to the papers by Truman and Kirkby and by Moore and Griffiths and to the second trough which they have discovered. This is rather disturbing in some ways, because the practical solution to this problem seemed to be heat-treatment at 1050°C. I am interested in the explanation of why it occurs. It has been suggested that boundary denudation may be responsible, but this boundary denudation occurs at much lower temperatures than the 750-1100°C test temperatures mentioned. In the case of the test-pieces aged at 850°C after solution treatment at 1350°C although this removed the first ductility trough it did not remove the second, although grain boundary denudation was observed in specimens tested at both temperatures. In the paper by Truman and Kirkby it is also mentioned that furnace cooling from 1350°C removed the low temperature trough and went some way towards removing the second trough. I should like to know if there were any differences in the micro-structure compared with specimens cooled more rapidly from 1350°C.

Mr Truman, in reply: With regard to the higher temperature ductility trough we showed in our paper, we pointed out that this may be caused by, and peculiar to, our particular testing procedure and conditions, and admitted that we did not understand it fully.

Nippes and his co-workers in the USA have carried out a considerable amount of work in trying to simulate the effects of welding cycles by heating test specimens to 2400-2500°F (about 1350°C) and cooling at rates corresponding to the cooling of weld heat-affected zone material after a single electrode pass during arc welding. This cooling rate is very rapid and during the cooling cycle Nippes rapidly fractured test specimens and measured ductilities at various temperatures down to around 815°C. Under these conditions, one might have expected him to show at least one of the ductility troughs we investigated; in fact, he showed no similar effects. The only low ductilities he showed were at temperatures in excess of 2400°F and persisted on cooling to test temperatures of 2000°F, these effects being attributed to grain boundary liquation at the higher temperatures.

In fact, the condition of our own tests differed significantly from those of Nippes, and from an actual weld cycle. Our specimens were rapidly cooled from 1350°C (air cooling in small section sizes) to room temperature, re-heated to test temperature in about 10 min, and held at test temperature for a further short period before straining. The conditions simulated by Nippes relate to the cooling following a weld pass on a block of metal, where the heat sink effect is great and cooling is very rapid. This gives a complete difference in conditions: very rapid cooling (in seconds) direct to test temperature in one case, and cooling to room temperature, followed by re-heating to test temperature over many minutes, in the other case. The different precipitation effects resulting from these two sets of conditions would be expected to give significant differences in ductility behaviour. Furthermore, we found no evidence that the higher ductility trough was associated with

strain-induced precipitation effects, as was the lower temperature ductility trough, this latter effect being a common feature reported by several investigators using slightly differing testing techniques.

With regard to the slower furnace cooling from 1350°C and the resulting improved behaviour in ductility at 1100°C, compared with that found after rapid cooling from 1350°C, there were significant differences in precipitation. With the particular cooling rate used, precipitation consisted of relatively few very coarse cubic particles of NbC. Rapid cooling from 1350°C, followed by ageing at 850°C, resulted in a fine dispersion of discrete particles of NbC (this type of precipitation is illustrated in two of the papers), which tended to coarsen slightly as the ageing time was increased. These differences in microstructure, i.e. the fine uniform dispersion of small NbC particles in one case, compared with the few very coarse particles resulting from the slow cooling, might be expected to give the differences in ductility behaviour found at 1100°C. In addition, one would expect that the slower cooling from 1350°C would result in more complete precipitation of carbide than would be obtained by rapid cooling and subsequent ageing for relatively short periods at 850°C.

As a general comment, it is worth noting that while all this work has been done to show the deleterious effects of niobium on ductility, it has been shown in practice that, despite these shortcomings, 18-12-1Nb steel can be successfully welded in large section, with the proper technique. It was interesting to see in the table of results obtained by the BWRA that every other steel covered showed higher resistance to heat-affected zone cracking than did 18-12-1Nb. These included other niobium-bearing steels and the inference is that they will be most probably superior to 18-12-1Nb in regard to welding behaviour.

Mr **Moore**, in reply: With regard to the solution treatment at 1050°C to which Mr Mitchell has referred, it would appear that providing it is possible to heat through the temperature range 550-850°C without cracking, prolonged ageing at 1050°C will not produce a structure which will affect the ductility at lower temperatures. In fact Messrs Truman and Kirkby have shown in their paper that pre-treatment at 1100°C does not reduce the ductility at 850°C.

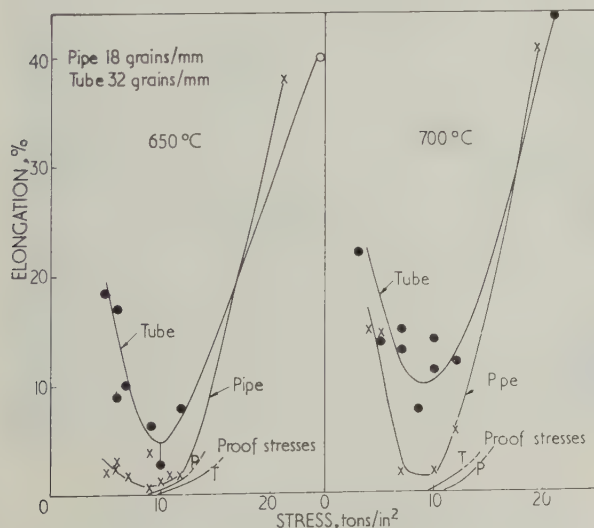
The second ductility observed at 1100°C was thought to be associated with the precipitation occurring at that temperature which resulted in the formation of niobium carbides. It appeared that the formation of large chromium carbides at the grain boundaries prevented niobium carbides nucleating nearby. From a study of the hot strengths of stabilized steels containing precipitates and unstabilized steels without precipitates, it appears that the relative differences in strength between a precipitate-stiffened grain centre and a denuded

grain boundary region will be greater at higher temperatures and more marked at 1100°C than at temperatures in the region of 850°C. Concentration of strain in the soft region near the grain boundary would lead to low overall ductility. The latter phenomenon is superimposed on the over-ageing/ductility-recovery process occurring between 850° and 1100°C, so that above 950°C the ductility falls once more. This downward trend of ductility continues up to 1100°C, beyond which the general lack of precipitation prevents the strain concentration effects referred to above.

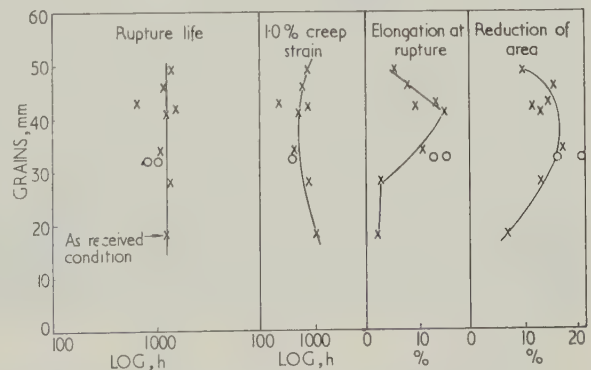
With this in mind, it is not surprising that a specimen aged at 850°C without strain and having grain boundary denuded zones still showed low values of overall ductility at 1100°C. Owing to over-ageing of the precipitates and the greater relative strength of the denuded zones at 850°C, the ductility was not reduced as much at this temperature. The reverse is also true, i.e. the denuded zones formed during straining at 1100°C did not cause excessive strain concentration when such a specimen was tested at 850°C and there was no sharp reduction of ductility.

Mr **Truman**: With regard to the effect of boundary denuded zones on the ductility behaviour reported, what struck me most forcibly about the micrographs of Moore and Griffiths was that the samples tested at 850°C, whether they had boundary denuded zones or not, did not show such zones in the micrographs. I am not sure from the work of Murray whether denudation of boundary zones was found with their bend tests at 850°C, but in the sequence of micrographs in the AEI paper the boundary denuded zones are becoming more prominent above 850°C, whereas the ductility levels begin to drop long before 850°C. One may imagine that at 850°C, over-ageing has set in to some degree, and probably the greatest effects from the strain-ageing mechanism are found in the samples approaching the 850°C ductility trough. Samples tested at 900-1050°C show well-defined boundary denuded zones and at 1100°C the bottom of the second ductility trough is reached. Whether or not boundary denudation effects are present after testing at 1100°C and higher, is difficult to say because of the rapidly decreasing amount of general precipitation at higher temperatures. What is interesting is the prominent boundary denuded zone on samples tested at temperatures between the two ductility troughs.

Dr **L. M. T. Hopkin** (National Physical Laboratory), speaking on behalf of himself and Mr **E. A. Jenkinson**: In general the NPL work agrees with that reported by Irvine *et al.* but there are details of interest. Figure 4 shows elongation/stress curves obtained at 650° and 700°C for two samples of 18-12-1 steel, one in the form of a steam pipe, the other a superheater tube. Both were air cooled from 1050°C. The first point is that at each test temperature the elongation of the two materials is markedly different; the difference is somewhat greater than the scatter shown by Irvine *et al.* for three casts. We believe this difference is related to difference of grain size; 18 grains/mm for the pipe and 32 grains/mm for the tube. It would be of



A Elongation/stress curves obtained at 650° and 700°C



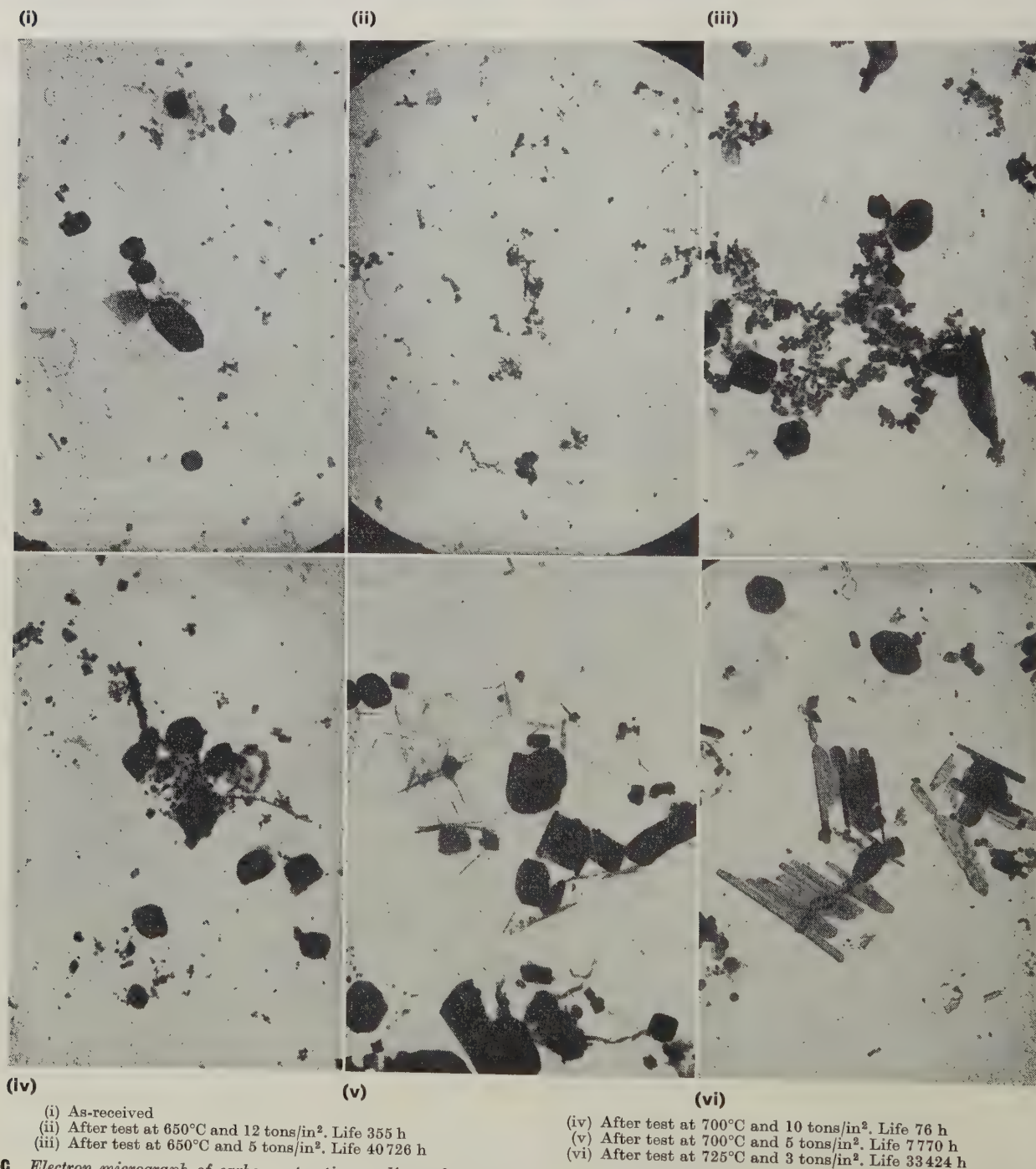
B Effect on creep properties of refining the grain size of the pipe steel. Creep tests 700°C and 7 tons/in²

interest to know the grain sizes of the samples tested by Irvine *et al.*

In view of the low ductility of the pipe material we have studied the effect of re-rolling followed by air cooling from 1050°C. Figure B shows that although the rupture life is not affected by grain size, refinement of grain size increases elongation at rupture. The circles plotted in this figure are the points for the tube material which agree fairly well with those for the rolled pipe samples indicating that the markedly different minimum elongations in Fig. A are probably related to difference in grain size.

It will be noted that the minimum elongation values for the pipe in Fig. A are particularly low; values below 1% often being obtained which are well below those obtained by Irvine *et al.* The pipe material at 650°C shows little tendency for the

elongation to recover; even after 40000 h a ductility of only 2% was obtained at a stress of 5 tons/in.² This is not observed at 700°C or by Irvine *et al.* Superimposed on these diagrams are the values of proof stresses for both materials. At 650°C it will be seen that the elongation at rupture of the pipe material is determined almost exclusively by the elongations on loading and little creep deformation takes place before rupture. In this case, therefore, the rupture time is controlled by the formation of a precipitate induced by strain on loading. On the other hand for the other elongation curves it will be noted that the extension on loading forms only a small part of the rupture elongation. Thus, contrary to Irvine *et al.* who consider that the minimum ductility is related to the strain on loading, the strains inducing precipitation before the minimum ductility is reached are substantially due to creep deformation. After the



C Electron micrograph of carbon extraction replicas of steam pipe

× 22000

TABLE 2 Compounds observed by X-ray and electron diffraction

Condition of material	Compounds present
<i>Pipe</i>	
As-received (AR)	NbC + Cr ₂₃ C ₆
650°C 12 tons/in ² 355 h	NbC + Cr ₂₃ C ₆
10 tons/in ² 796 h	NbC + Cr ₂₃ C ₆
9 tons/in ² 1581 h	NbC + Cr ₂₃ C ₆
... 5000 h	NbC + Cr ₂₃ C ₆
7 tons/in ² 5709 h	NbC + sigma + Cr ₂₃ C ₆
5 tons/in ² 40726 h	NbC + sigma + Cr ₂₃ C ₆
700°C 10 tons/in ² 76 h	NbC + Cr ₂₃ C ₆
7 tons/in ² 1220 h	NbC + Cr ₂₃ C ₆
... 5000 h	NbC + sigma + FeCr ₂ (Nb) + Cr ₂₃ C ₆
5 tons/in ² 7770 h	NbC + sigma + FeCr ₂ (Nb) + Cr ₂₃ C ₆
... 10000 h	NbC + sigma + FeCr ₂ (Nb) + Cr ₂₃ C ₆
4 tons/in ² 18826 h	NbC + sigma + FeCr ₂ (Nb) + Cr ₂₃ C ₆

minimum elongation is passed and the ductility begins to recover, precipitation may still be principally induced by the creep strain but at such low rates of strain the concentration of dislocations is small and the corresponding particle size of the precipitate coarse.

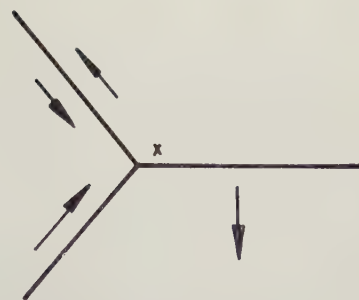
In general we have found a similar correlation between precipitate particle size and the elongation curve as reported by Irvine *et al.* This is shown in Fig. C (i-v). It will be noted that the NbC forms in characteristic cuboidal fashion even when on dislocations. At long times of test when the ductility is recovering, in addition to NbC, sigma also forms and eventually is replaced by another phase shown in Fig. C (v) and (vi) which is believed to be FeCr₂ containing some niobium. It is often thought that the presence of sigma induces brittleness but Table 2 shows clearly that both sigma and FeCr₂(Nb) do not appear until well after the minimum in ductility when the elongation is increasing.

Finally, it has been suggested that the presence of a denuded zone resulting from carbide precipitation at grain boundaries contributes to rupture with low elongation. This idea must be reconciled with the belief that in Nimonic alloys similar grain boundary denudation allows increased deformation in the grain boundary region resulting in greater rupture elongation.

Mr Murray, in reply: I believe, and I know that my colleagues agree, that the effect of grain size on the rupture strength and ductility of an austenitic steel is very small indeed. The evidence for this can be obtained from the literature. It has been shown that there is very little variation in the rupture strength and ductility of an unstabilized steel (18Cr-8Ni) when the solution treatment temperature is varied between 950° and 1200°C. On the other hand, when such treatments have been carried out on the Nb-stabilized 18Cr-12Ni steel there has been a marked change in the rupture properties. As the solution treatment temperature was increased, the rupture strength progressively increased and the ductility decreased. In both steels the grain size progressively coarsened with the increase in solution treatment temperature; consequently since in one steel the properties remain constant while in the other they markedly vary, the grain size cannot be considered as a major factor. The major factor controlling the strength of the 18-12Nb steel is the amount of Nb in solid solution and this can be varied by variation in solution treatment. The major effect from the Nb is not its solution hardening potential but rather that the amount in solid solution governs the amount of NbC that can be precipitated subsequently.

Results on the superheater tube and steam pipe material that Dr Hopkin mentions have been the subject for discussion at various committees. It has often been stated that the heat-treatment cycle on tube production is very different from that for large steam pipe. I believe his results would be perfectly explained if the soluble Nb contents of the respective tube and pipe samples were determined.

Dr Hopkin: Mr Murray believes that there is no effect of grain size in this material and that the effects shown in the NPL

**D** Schematic diagram showing grain boundary sliding under an applied stress

results are due to differences in solute NbC contents. The samples for which the effect of grain size is shown in Fig. B were obtained by repeated soaking and rolling at 1050°C and there can be little doubt that they all had similar soluble NbC contents.

Mr Murray, in reply: If the time cycle and the temperature cycle are varied the soluble niobium content will vary also. I do not think that the time cycle at any one particular temperature is as critical as you suggest, but you must remember that we are talking not of differences of a few minutes but of quite considerable differences. It is a very much more difficult job to solution treat heavy steam pipes, raising them to a certain temperature and keeping them there, than it is to treat small diameter thin-walled tube.

Mr Kirkby, in reply: On the subject of grain size, I find myself in the position of agreeing and yet disagreeing with Mr Murray. I agree that the effect of grain size in 18-12-1 Nb steel is small or negligible if all other factors are ignored, but if grain size is considered in relation to a particular solution treatment, then the effect of grain size could be significant. In other words, the type of data shown by Dr Hopkin can be obtained on bars with different grain sizes but with the same degree of solution, i.e. the same final solution temperature.

The point made by Dr Hopkin concerning the data obtained on pipes and tubes is also confirmed by our own work, in which 1050°C treated pipes were found to have a rupture ductility of 1-2% at 650°C. Further soaking at temperatures of 1050-850°C does not raise the ductility. Material (bar or pipe) solution treated at 1350°C and air cooled has the same poor ductility, but furnace cooling from the same temperature gives a much better ductility, so that it is rather complicated. The degree of solution of NbC is obviously important and has in itself an important influence on ductility and creep resistance. It is clear, however, from data which are accumulating that the relationship of grain boundary area to grain matrix, i.e. grain size, must have some bearing on ductility, since it has been shown that NbC stiffens the matrix relative to the boundary.

Mr Murray, in reply: I said that it was possible to get small differences due to grain size, but in this case we are talking about major effects. The major effect in my view is the amount of Nb in solid solution. We can get many interesting effects by permutating heat-treatments, but until we determine the Nb in solid solution after such treatments we shall not get a clear answer.

Dr Baker, in reply: Continuing on the subject of grain size; if we have a situation as shown in Fig. D grain boundary sliding will lead to stress concentration at x. If the surrounding grains are able to deform, the stress concentration at x will remain small. However, if the grains are stiffened in any way, such as by strain-induced precipitation, stress concentrations at x may become sufficiently large to cause cracking. This is the basis of what we say in our paper, that the grains are made sufficiently stiff in these niobium steels. We might consider

that if the grain boundary were completely free of any foreign matter, a large grain size would be detrimental. The larger the boundary on which sliding occurs, the greater the stress concentration at the grain corners and the greater the susceptibility of the steel to cracking. There is, however, another factor to be considered, and that is particles at the grain boundary. Their effect is not entirely clear in these steels, but there are two things to which I should like to draw attention. If we increase the grain size we decrease the total grain boundary area, and therefore if we have a given amount of precipitate we can put the particles closely together. This might be expected to offset at least in part any deleterious effect due to the large grain size. The other point concerns the denuded zones which have been observed at the boundaries and which might perhaps be expected to have some effect on the ductility. They probably do, but not during heat-affected cracking, for this reason. In all our observations we have observed cracking to occur only at the very beginning of the precipitation process, and we have observed these denuded zones only in a comparatively over-aged condition. I say 'comparatively' advisedly, because there is still, or can be, considerable creep resistance in a steel with denuded zones.

Mr B. Goldthorpe (Fulmer Research Institute Ltd): I think that grain size comes in because of its effect on the proof stress.

Mr Murray: It is known that variation in grain size can have an effect on the proof stress. However, there has to be a large variation in grain size before the effect becomes pronounced. In this case we are dealing with, the 18-12-Nb steel which is normally supplied has a relatively small variation in grain size. Collected data from a number of steelmakers indicates that the 0.1% proof stress varies from 12.5 to 14.4 tons/in² at 20°C and from 8.4 to 9.5 tons/in² at 650°C.

Mr Goldthorpe: You make the point that the minimum ductility occurs with 0.1% proof stress, and this is very dependent on the grain size. One would not expect this effect in an unstabilized steel because there is not a pronounced minimum in the elongation *v.* stress-to-fracture curve.

Mr F. E. Asbury (Central Electricity Research Laboratories) commented on the effects of recrystallization, which had not been mentioned in the papers. **Mr Truman** replied. Mr Asbury's comments were later submitted as a written contribution to which Messrs Truman and Moore replied in writing: these contributions can be found on pp.303-305.

Dr Irvine, in reply: One of the features of this meeting which interests me is the emphasis there has been on the use of electron microscopy. It has been shown that this technique can be of great assistance in providing the answer to essentially practical problems. This symposium has shown the value of this technique quite clearly and this should encourage many other laboratories to equip themselves for this work.

There is a considerable measure of agreement between the different authors on the different mechanisms involved, and it is noteworthy that this mechanism has not been mentioned in any of the previous American and Russian work. However, since this previous work has made no use of electron microscopy, this is not surprising.

Many people at this meeting, having heard the suggestion made that 18-12-1 steel is too near the borderline of susceptibility to cracking to be satisfactory when thick sections must be welded, must be asking themselves what material is suitable. It should be emphasized that the properties of 18-12-1 steel are borderline and not completely satisfactory. Mr Mitchell has shown that reasonable success can be obtained providing adequate care is taken. However, assuming that a better steel is required, then there are some quite definite metallurgical alterations which can be made, which will give better ductility.

Grain boundary denudation may be a contributing factor to brittleness and modifications can be made to the composition to limit this grain boundary denudation.

The amount and intensity of precipitation can also be controlled together with the degree of misfit between the lattice of the carbide which is precipitating and the lattice of the matrix from which the carbide is precipitating. Austenitic stainless steels have recently been developed with these points in mind and have shown considerably improved ductility.

Finally I should like to give a word of warning relating to the interpretation of electron microstructures. Great emphasis has been placed in these papers on the harmful effects resulting from strain-induced precipitation. This is not the case and in fact such precipitates are essential to provide adequate strength. It must be emphasized that what is important is the stress system produced by the precipitation.

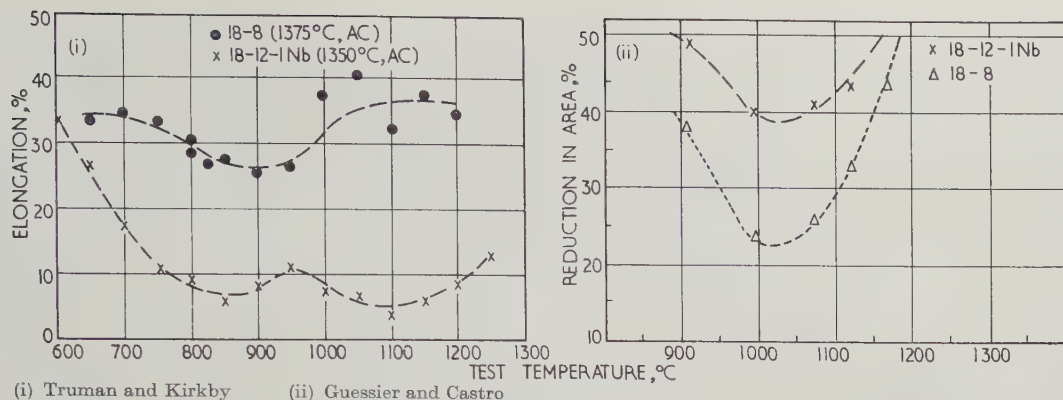
Mr R. Rolls (Manchester College of Science and Technology): Messrs Younger and Baker have shown that for the 18Cr-10Ni-3Mo steel (containing 0.04%C) little or no intragranular precipitation was observed in the deformed and aged specimens after treatment for up to 100 h at 750°C, whereas for the 18Cr-12Ni-1Nb steel (containing 0.085%C), similarly treated, an intragranular precipitate of NbC was found. It would appear, as the authors have recognized, that carbon content may be significant in its effect on these results. Have the authors clarified the position yet by investigating the influence of higher carbon levels on the Mo-containing steels?

Mr Younger, in reply: We have only studied the effect of carbon content in an unstabilized steel. On lowering the carbon content from 0.08% to 0.023% the susceptibility to cracking was found to be slightly increased.

Dr L. E. Benson (AEI Ltd): With regard to what has been said about the use of the electron microscope, we are used to our friends across the Atlantic being ahead of us in running into trouble, and it is nice to think that we may be a little ahead of them in getting out of it!

Mr Younger: It would seem to have been very clearly shown in these papers that strain-induced precipitations can have a marked effect in raising creep strength, and that this may result in a lowering of creep ductility. I should like to suggest that in this type of material this is not the only means by which these ends may be reached. As far as creep strength is concerned, there is some evidence that it is possible to get some degree of creep resistance in steels in which no strain-induced precipitate has yet been detected (e.g. type 316). Regarding creep ductility, Truman and Kirkby have shown that it is possible to get low ductility at high temperatures (1100°C) where only very sparse strain-induced precipitation is found. Both these facts suggest that there is a second grain strengthening mechanism in operation. Furthermore this high-temperature ductility dip behaves in a rather different manner from the dip at 850°C, since it does not respond in the same way to pre-conditioning of the material. Its second difference can be seen in Fig. E(i) and (ii). Figure E(i) shows the Truman and Kirkby measurements of high-temperature ductility. The ductility of the 18-8 steel is consistently above that of the 18Cr-12Ni-1Nb steel. Figure E(ii) comes from some French work by Guessier and Castro.¹ Here the position is reversed and the ductility of the 18Cr-12Ni-1Nb steel is consistently higher. It is strange that by two different testing methods we can completely reverse the position of the curves. However, it is interesting to note that the results in the first figure were obtained by testing at a strain rate of about 10⁻³; while in the second case it was very nearly 10¹.

It therefore seems that this high-temperature ductility trough is dependent on elements in solid solution and is also very sensitive to strain rate. Both these suggest that it may be a dynamic strain-ageing effect. Very little experimental work has been done on this effect in austenite, but if we transfer the figures which have been obtained by Cottrell,² first with nitrogen in iron and secondly with substitutional elements in aluminium and iron, we obtain the results shown in Table 3. This table gives the minimum calculated temperature at which



E Ductility of tensile specimens tested at two different strain rates

dynamic strain ageing might be expected. In the case of the chromium steel, using the figures for the diffusion rate of chromium in austenite and assuming that the vacancy supersaturation is very small, the minimum temperature is 950°C. For the niobium steel the minimum temperature is 850°C. The correlation between these figures and the experimental facts is quite encouraging.

Mr Truman, in reply: My only comment is that this is probably dependent on strain rate. In the work referred to there was an unusually fast strain rate.

Mr Pickering: Can Mr Truman say whether the fracture produced during the second high-temperature minimum in the ductility curves is intergranular? If it is, could not this ductility minimum be the result of a segregation of, for example, Nb atoms to the austenite grain boundaries? This could perhaps lead to an intergranular rupture with low ductility which might be considered analogous to intergranular embrittlement in Fe-N alloys at very much lower temperatures.

Mr Truman, in reply: The fracture is definitely intergranular at the high-temperature end and it is round the original high-solution treatment boundaries, not any recrystallization boundaries which may be introduced.

Mr Younger, in reply: I do not feel that this is a very difficult problem. In the steels that we have been considering in the three papers it is possible by stiffening the grains to get intergranular fracture.

Mr E. A. Brandes (Fulmer Research Institute): On the 20-20 steels, which have shown effects very similar to those shown by the authors, we did some experiments on which we should like to have their views. We solution treated at 1300°C with quick cooling, and strained the specimens at 800°C by various amounts. At 800°C short-time tests showed low ductility. We then cooled to room temperature and pulled at room temperature and found that all the room temperature tests showed no loss of ductility at all, that is after 1300°C solution, quick cooling, straining, and ageing at 800°C. Can we have comments on that?

Mr Truman, in reply: We have covered this in relation to the 850°C ductility trough on 18-12-1Nb steel, where we rupture with 6-10% elongation after the high initial solution treatments. We have strained test-pieces about 3% at 850°C, then broken them at 600°C. Even though the specimens con-

tained shallow surface cracks after straining at 850°C, the ductility at 600°C was not catastrophically low. A further series was strained 3% at 800°, 825°, and 850°C, and on re-testing smaller specimens machined from the original strained specimens, at 600-800°C we obtained ductilities not far removed from the original curve. This does not necessarily imply that ductility generally at lower temperatures could not be affected by pre-straining at 800-850°C, merely that it was not affected at the particular strain rates used. It could be affected at slower strain rates and further work is needed here.

We did not re-test at room temperature after straining at 800-850°C, but re-tests at 600°C broke with about 3% elongation.

We carried out similar tests after straining 2% at 1100°C and then re-testing at room temperature upwards; again ductility was not affected by the pre-straining under the test conditions used.

Dr Baker: I think that perhaps the reason why induced NbC precipitate has such a large effect at high temperatures may be that it is affecting the strength of the grains in relation to the grain boundaries in a system where we get both deformation in the grains and deformation of the grain boundaries during creep relaxation. At room temperature there would be little or no grain boundary sliding; deformation of the mass as a whole would occur and one would not expect a large falling off in ductility, though there might be a slight effect owing to the stiffened nature of the whole. Where the strength of the grains in relation to the boundaries comes into prominence again is at very low temperatures, where in impact tests the presence of the strain-induced precipitation in the grain might lead to the appearance of a ductile-brittle condition and grain boundary fracture.

WRITTEN CONTRIBUTION

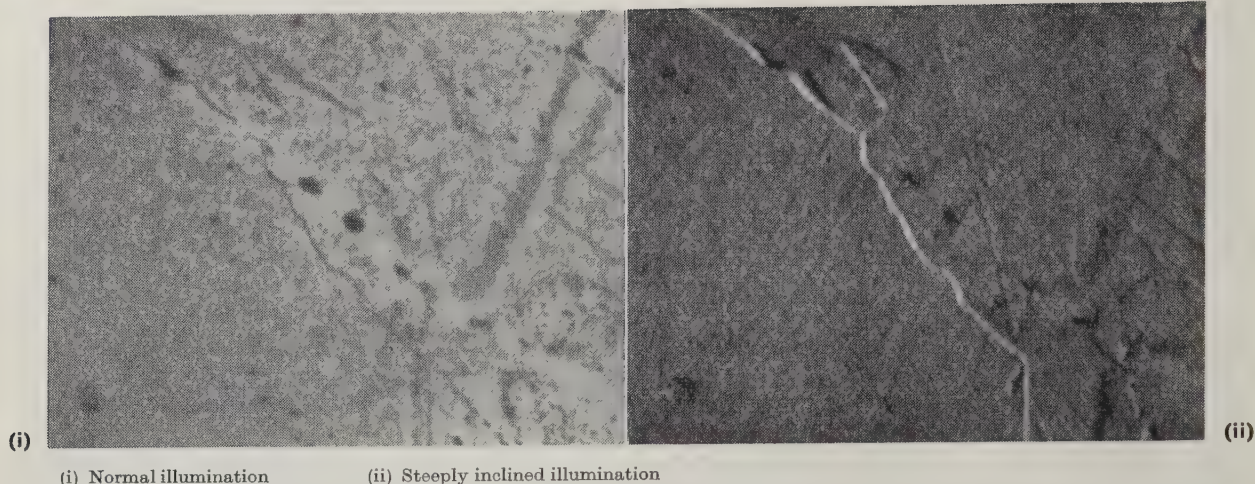
Mr F. E. Asbury (Central Electricity Research Laboratories) wrote: * Some of these papers draw attention to the possible effects of the intergranular precipitation of niobium carbide and the absence of this precipitate in regions adjacent to grain boundaries. None of them, however, considered the effect of the migration of grain boundaries which may take place at temperatures above 850°C in this steel. Some recent work carried out at CERL indicates the effect of such movements on the microstructure.

We have solution treated a typical 18Cr-12Ni-1Nb steel at 1230°C, air-cooled it, and applied about 35% tensile strain at room temperature. Small pieces were then reheated rapidly to temperatures between 650° and 1200°C, and held at temperature for 1 h, after which they were air-cooled. The material was recrystallized and softened between 850° and 1050°C, the grain size decreasing from ASTM no.2 to ASTM no.7. Specimens were examined on the optical microscope, under normal illumination and steeply inclined (oblique pencil)

* This correspondence was received before the meeting took place.

TABLE 3 Calculated minimum temperature for strain ageing effects in austenite

$\dot{\epsilon}$	Cr (20 at.-%)	Nb (0.5 at.-%)
$10^{0.7}$	950°C—	1320°C—
10^{-8}	400°C—	850°C—



F 18Cr-12Ni-1Nb steel solution-treated, strained 35% cold and heated for 1 h at 950°C, showing grain boundary breaking away from precipitation pattern × 2000

illumination. Under the latter, grain and twin boundaries are emphasized.

The specimens heated at 650–850°C showed only an intergranular precipitate and strain bands. That heated at 950°C showed an intragranular precipitate, regions devoid of precipitate next to the grain boundaries, and a grain boundary precipitate. However, the material had clearly started to recrystallize after the intra- and intergranular precipitates had first formed, and the grain boundaries were only partly related to the pattern of precipitation (see Fig. F(i) and (ii)). The specimen heated at 1050°C showed similar but heavier precipitation to that heated at 950°C, and the grain boundaries bore no relation to the pattern of precipitation (see Fig. G(i) and (ii)). The material had completely recrystallized after the precipitates had formed. Such effects could be missed on extraction replicas prepared for examination on the electron microscope, if the grain relief was not clearly revealed by the replica.

We have found similar structures in the heat-affected zone of a fillet weld in an 18Cr-12Ni-1Nb steel, which had been given a post-weld heat-treatment of 1 h at 1050°C (Fig. H(i) and (ii)). Near the surface the contraction strains of the weld were concentrated in the heat-affected zone by the notch arising from the weld profile, and recrystallization occurred after the precipitation of carbides during the post-weld heat-treatment.

It is reasonable to suppose that grain boundary movements, giving rise to similar structures also occur in hot tensile and hot bend test-pieces strained at sufficiently high temperatures.

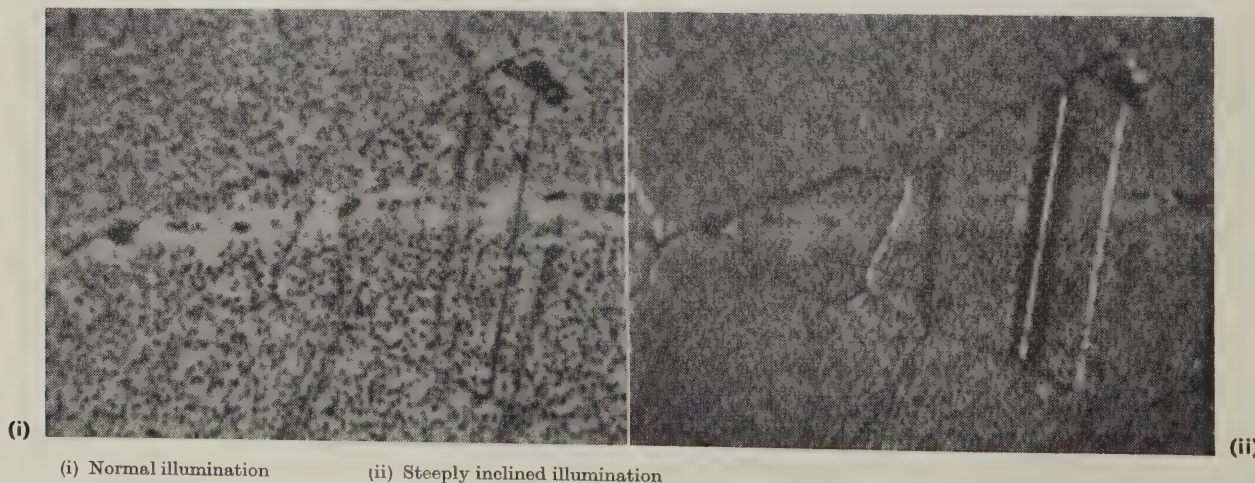
We should like to suggest that the improvement in ductility in 18Cr-12Ni-1Nb steel as testing temperatures are increased from 850° to 1050°C as suggested in the papers by Irvine *et al.* and Truman and Kirkby, may not be due only to the effect of a coarser and more dispersed precipitate, but also to the migration of the grain boundaries from the zones depleted in niobium carbide.

AUTHORS' REPLIES

Mr Truman wrote: We would agree that we have not paid particular attention to recrystallization as being a contributory factor in ductility recovery at temperatures above 850°C. It is quite probable that this phenomenon does to some extent contribute to ductility recovery, as Mr Asbury's evidence indicates, but we still feel that this plays a relatively minor role compared with the recovery effects associated with over-ageing of the intergranular precipitation of niobium carbide.

Figure I compares the short-time tensile ductility behaviour of 18-12-1Nb in the 1350°C AC, 1350°C AC+16 h 850°C AC, and 1350°C AC+1 h 1050°C AC conditions.

The ductility trough at about 850°C resulting from the 1350°C AC treatment is removed almost completely by pre-ageing at 850°C or 1050°C before testing. In the case of the 1350°C AC condition, slight recovery occurs above 850°C, but after the above pre-ageing treatments, the ductility in fact begins to drop at test temperatures above 850°C, resulting eventually in the second trough at 1100°C discussed in our paper.



G Steel solution-treated and strained as above, but heated 1 h at 1050°C, showing a recrystallized grain structure mostly unrelated to the pattern of precipitation × 2000



(i) Normal illumination (ii) Steeply inclined illumination
H Heat-affected zone of fillet weld in 18Cr-12Ni-1Nb steel. The weld has been heat-treated for 1 h at 1050°C, and the pattern of precipitation is only partly related to the grain structure $\times 2000$

This evidence compares tests from the same cast, with the same initial grain size, but with differences in the amount of niobium carbide in solid solution. While not conclusive, it does tend to indicate that carbide solution and precipitation is the main feature affecting the shape of these ductility curves rather than recrystallization above 850°C. It is probable that the tendency towards recrystallization under the same conditions may be governed to some degree by the amount of carbide in solid solution, but it is anticipated that recrystallization to some degree will occur in both the solution treated and pre-aged series of tests above 850°C. In effect, the tendency to recrystallization at temperature in the pre-aged series should be much greater than in the solution treated series, because of the higher strains applied to the former series before fracture.

Mr Moore: Mr Asbury's comments on the recrystallization phenomena he has observed are very interesting, as are the possible effects they may have on the hot ductility of 18-12-1Nb steel. It is possible that recrystallization may contribute to the slight restoration of ductility above 850°C during hot tensile testing. It is felt, however, that precipitation effects exert a greater influence.

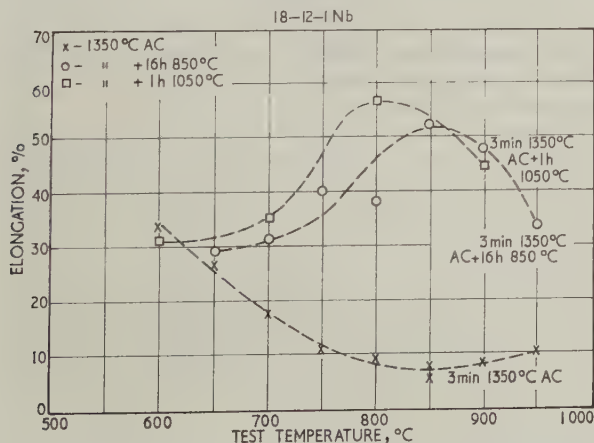
We have studied the room temperature hardness values of the hot tensile specimens. Both macro- and micro-hardness tests were carried out and each point on the micro-hardness curve represents the average of 20 or so impressions taken from grain centres and grain boundary regions. The results together with the corresponding ductility values are shown in Fig. J. This shows that the specimens previously tested at 650° and 750°C have high values of hardness while the speci-

men tested at 800°C was considerably softer. A sharp rise in hardness was observed in the specimen tested at 850°C, which was the temperature at which the finest dispersion of niobium carbides was seen and the low-temperature ductility trough experienced. The hardness of specimens previously tested between 900° and 1100°C continued to fall as the precipitates became more widely spaced and larger in size. There was a slight increase in hardness in the specimen previously tested at 1200°C, as increased solid solution hardening resulted from the small amount of precipitation occurring during the tensile test.

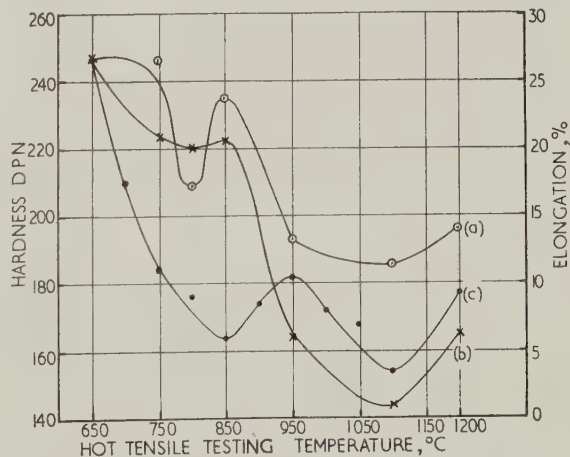
No signs of recrystallization, such as those described by Mr Asbury, were observed in the specimens we examined. If recrystallization had occurred in the specimens it would appear to have taken place before precipitation and its effect to have become obvious at temperatures between 750° and 800°C. However, it was at temperatures above this, 850–1100°C, that the more marked changes in ductility, micro-structure, and hardness were observed. This would indicate, at least under these testing conditions, that it is precipitation effects and not recrystallization phenomena which are the controlling factors in the loss of ductility of 18-12-1Nb steel at 850°C and the subsequent slight recovery of ductility at 950°C.

REFERENCES

1. A. GUESSIER and R. CASTRO: *Rev. Met.*, 1958, **55**, 107–122.
2. A. H. COTTRELL: 'Creep and fracture of metals at high temperatures', 141; 1956, HMSO (for National Physical Laboratory).



I Short-time tensile ductility behaviour of 18-12-1Nb under various conditions



J Relationships between RT microhardness, curve (a) macro-hardness, curve (b), and hot ductility, curve (c)

A note on brittle fracture initiation in mild steel by prior compressive pre-strain*

Dr **S. A. Main** wrote: The problem of catastrophic failure in service of steel plating through utterly brittle behaviour remains an important one. The paper by C. E. Turner gives rise once more to the question whether measurement of the brittle strength of a distorted and/or notched specimen can ever be of any real use towards its solution.

It may be asked whether any test providing a specific degree of priming and promoting failure at a temperature dictated by the form and physical condition of the test specimen, can simulate the conditions existing in service; that is, at the critical location in all, or even in any one, of the innumerable structures with their varied constructional features and service. Can it also be said that such a test will discriminate reliably between two batches of steel plating under consideration, as regards their respective prospects of survival in a particular structure and its proposed service?

A very slight and superficial plastic strain is a necessary prelude to the start of a brittle fracture. Any test of the kind mentioned, by emphasizing this priming action, only does so by superposing a complicated system of stresses and strains, of a kind peculiar to itself, and accordingly affecting the value of the strength figure so assessed.

The one essential factor in brittle behaviour is triple tensile stress; it is this combination which all tests so far intended for practical use manage, however clumsily and confusedly, to effect. Should not therefore the efforts of metallurgists be directed to the devising of a test providing simply this combination of stresses; that is, on undeformed steel and without the complication introduced by such features as notches, and capable of determining brittle strength at any selected temperature within a prospective range of service? In such circumstances the steel is quite capable of providing the necessary priming. Such a test, once established, would provide a figure representing the brittle strength of the steel against failure in its most catastrophic form; that is where it can, and does, occur without previous imposed deformation.

That the problem is no doubt a difficult one should not be a deterrent but a challenge. Only in this way can such testing be placed upon a rational basis; that is providing, like the ordinary tensile test in its own applications, a basic figure to which a factor of safety (assessed as best possible on judgment of the design and workmanship of the structure and its conditions of service) can be applied.

AUTHOR'S REPLY

Dr **C. E. Turner** wrote: It is difficult to reply fully to Dr Main's comments without writing a paper several times the length of the original note. Some answer can, however, be made at two levels: general points to which a brief reply will be given and specific comments on the present paper.

There is no doubt that brittle fracture is a difficult problem. The voluminous literature on the subject shows clearly that

many workers have indeed accepted it as a challenge and not a deterrent. That their combined efforts have not so far produced either a complete solution or even a universally accepted test, triaxial or otherwise, encourages other workers such as the present writer to contribute what small amounts they can towards a fuller understanding. It may be questioned whether a triaxial stress test is a final or even desirable goal of brittle fracture workers and indeed to what extent on a macroscopic scale such a concept is meaningful. In examining the notch-brittle behaviour of steel there seems every reason for using both a notched test-piece and testing temperatures below the so-called ductile-brittle transition temperature (however this may be defined). The magnitude of this temperature for a particular steel is vital for service requirements but probably largely irrelevant in relation to the present tests.

The tests reported, however, do not purport to measure the brittle strength of distorted steel as a direct yardstick of the behaviour of the undistorted steel, though it is interesting to speculate whether the derived G_c value is comparable to that of the virgin plate. It was not claimed that such a test would discriminate usefully between two service batches of steel, although the degree of susceptibility to such prior damage may in fact be of great interest. It is suggested that (as pointed out by Mylonas¹) the notching and prestraining simulates conditions which may arise during fabrication.

It has been implied in the interpretation of the test results that the concept of a cleavage crack propagating at relatively low stress levels in mild steel, below the ductile-brittle transition temperature, is accepted, and that there is some quality of the steel as yet but imperfectly understood which prevents such a crack starting simply under the conditions at which it is known to propagate. The term 'initiation barrier' has been applied to this concept. It is suggested that the prestraining action produced here effectively reduces this initiation barrier, so that the start of cleavage crack is more likely under low applied stress. The metallurgical nature of the change or damage induced is not known: quite obviously further work both on notched and unnotched material is required to elucidate this.

It is interesting to note that sectioning a prestrained test piece, fractured at low stress, does not reveal the usual indications (by optical microscope) of a few crystals sheared at the start of the crack before the onset of cleavage. However, this is a metallurgical field which, as an engineer, I am wary of entering.

The discussion of cleavage fracturing of mild steel plate in the light of various initiation processes followed by an overall crack propagation mechanism (whatever the microscopic concepts involved) seems to provide as rational a basis for understanding the macroscopic phenomenon as any other ideas yet put forward.

REFERENCE

1. C. MYLONAS *et al.*: *Weld. J. Res. Suppl.*, 1958, **23**, 473s-479s.

* C. E. TURNER: *JISI*, 1961, **197**, 131-135.

Strain ageing and the fatigue limit of steel*

Dr **D. Cratchley** (Rolls-Royce Ltd, Derby) and Mr **J. Smith** (Safety in Mines Research Establishment, Ministry of Power, Sheffield) wrote: It was with great interest that we noted the evidence put forward by Levy and Kanitkar indicating that the definite fatigue limit observed in mild steel is due to the ability of that material to strain age harden during the fatigue test.

We are ourselves in the early stages of an investigation into the effects of static and dynamic prestrain upon the fatigue properties of the materials used in the manufacture of colliery haulage and suspension gear, e.g. 1.5% Mn mild steel and 25-30 carbon steel.† This programme was designed to determine the effect of the excessive static and impact loads which are frequently superimposed on the more or less continuous fatigue loading to which this gear is subjected.

Our specimens are either dynamically strained to the requisite degree ($\pm 4, 9$, and 17%) in a modified Charpy impact machine or statically strained to the same extent in an ordinary tensile testing machine and then held for 8 h at 100°C to achieve the fully-aged condition. All fatigue tests are carried out on the same Schenck 2-ton pulsator and the results are expressed as S/N curves for the material in each strained and fully aged condition which can then be compared with the S/N curve for the virgin material.

Figure A shows the S/N curves about zero mean stress for the unstrained materials, both of which exhibit a sharp 'knee' at about 10^6 cycles of stress; there being no failure between 1.7×10^6 and 10^7 cycles when all surviving tests were terminated. This value of 10^7 was decided upon because of the rather low, 2600/min, frequency of the machine; for this reason too the number of points taken in determining the S/N curves is

considerably less than that of Levy and Kanitkar. However, in spite of these deficiencies the knee is quite well defined. So far, only the manganese steel has been tested in the strained and fully aged condition but the results do show that the sharp knee is removed and failures have been observed between 10^6 and 10^7 cycles (Fig. B) in the specimens strained 9% and 17% although those strained 4% still exhibit a knee.

Further confirmatory evidence comes from similar work by Sander and Hempel‡ who observed sharp knees at 10^5 cycles for unstrained mild steel and at 5×10^5 cycles for a $0.4\% \text{C}$ steel with complete absence of failure beyond these test durations. On fatigue testing these steels after prior tensile strain, 17 failures of mild steel and 20 of the $0.4\% \text{C}$ steel are observed between 10^5 and 10^7 cycles, although in fact all the curves have been drawn with sharp knees.

The present results seem to confirm that as the capacity for strain ageing becomes exhausted, in this case by tensile strain followed by ageing as opposed to the coxing treatment given by Levy and Kanitkar, the distinct fatigue limit is removed.

AUTHOR'S REPLY

Mr **Levy** wrote in reply: The work presented by Dr Cratchley and Mr Smith is especially noteworthy in view of the practical implications mentioned in their second paragraph. Study of the alteration in fatigue properties by either accidental or deliberate strain ageing may, for example, provide an argument for the 'running-in' of machinery at low loads before full load is applied. In effect a coxing procedure is thus carried out.

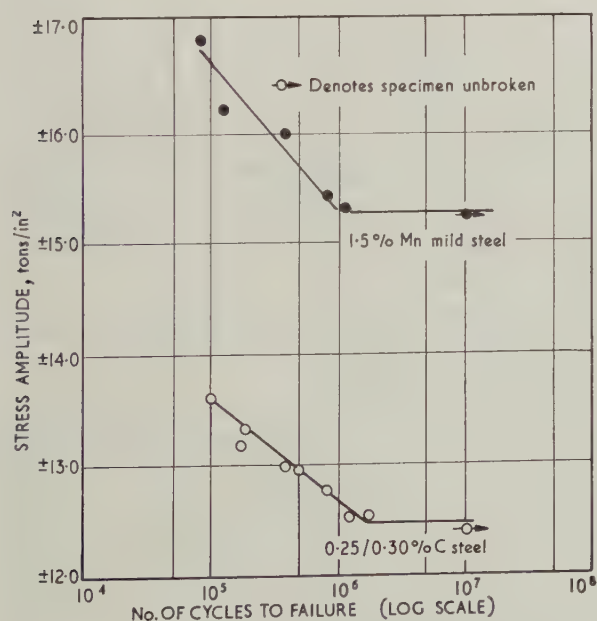
An additional feature worth pointing out is that the top curve of the second figure in the communication can be superimposed almost exactly on the top curve of Fig. 8 in the paper.

Finally it is opportune to mention a small error in the composition of the steel as printed in the paper. The Ni should be N.

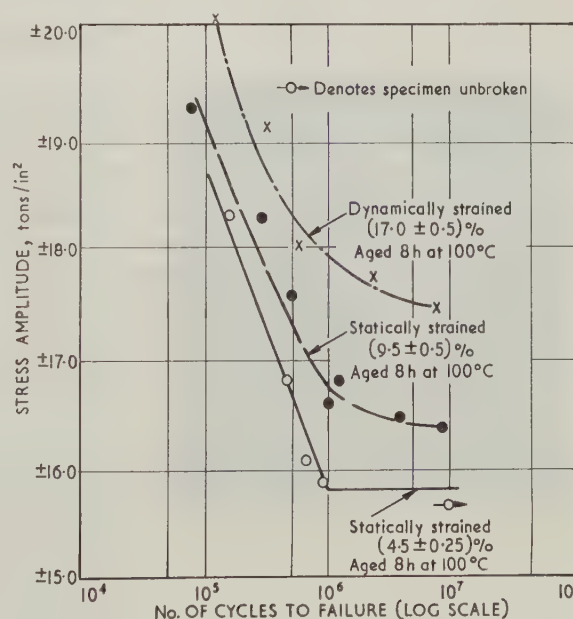
* J. C. LEVY and S. L. KANITKAR: *JISI*, 1961, **197**, 296-300.

† B.S.2772, (II), 1956.

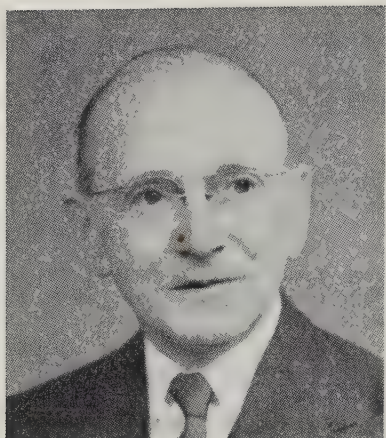
‡ H.-R. SANDER and M. HEMPEL: *Arch. Eisenh.*, 1952, **23**, 299-320.



A S/N curves about zero mean stress for the unstrained materials as normalized



B S/N curves about zero mean stress for normalized 1.5% Mn mild steel after straining and ageing. Note: Figs. A and B are Crown Copyright



Dr T. P. Colclough, C.B.E.

Dr T. P. Colclough, C.B.E., an outstanding figure in the British iron and steel industry, died at his home in Buckinghamshire on 22 September, aged 75.

Tom Peach Colclough was educated at the University of Manchester, where he specialized in organic chemistry and was awarded the degree of M.Sc. in 1906. He entered the steel industry in 1916, when he took up the appointment of chief chemist at the Brown-Firth Research Laboratories under the late Dr Hatfield. Two years later he was awarded an Associateship and a Mappin Medal in Metallurgy at the University of Sheffield, and in 1920 he graduated in metallurgy. The degrees of D.Sc. of Manchester University and M.MET of Sheffield University were awarded to him in 1937, and in 1959 he was awarded the degree of D.MET. by Sheffield University.

He joined the Park Gate Iron and Steel Company Ltd in 1920, and during the following nine years held the positions of chief chemist, chief metallurgist, open-hearth manager, and technical officer. His next appointment was as technical director to H. A. Brassert and Company Ltd, a position which he held until 1942. During this time he took part in the development and building of several steel-plants, including the Corby works of Stewarts and Lloyds Ltd, and the Ebbw Vale works of Richard Thomas and Baldwins Ltd.

Dr Colclough studied iron-ore and coal mining and iron and steel manufacture in the USA and in most of the countries in Europe; he visited China in 1936 and New Zealand in 1939 to report on the establishment of national steel industries in these countries. For a time he held the post of technical adviser to the Hermann Goreing works in Germany and Austria and the Turkish steelworks at Karabuk. During the Second World War he was appointed technical adviser to the Iron and Steel Control, Ministry of Supply. From 1945 to 1949 he was technical adviser to the Control Commission in Germany, and in 1947 he was awarded the C.B.E. for his services to the Ministry. He became technical adviser and consultant, and later chief technical adviser to the British Iron and Steel Federation, assisting in the preparation of its development programmes, and he was a member of the Technical Advisory Panel of the Iron and Steel Board.

A man of truly international vision, he served as technical adviser to the ISCON project at Durgapur and was a member of the Royal Commission on the steel industry of Southern Rhodesia. In recent years he led BISF missions to the USSR, Poland, and Yugoslavia.

Dr Colclough was elected a member of The Iron and Steel Institute in 1921. He represented the Institute on the Council of the British Iron and Steel Research Association from 1949 to 1952. He was a member of the Ironmaking Panels of the Association from 1945 to 1952, and later chairman of the Steelmaking Panel.

In 1954 Dr Colclough was awarded the Bessemer Gold Medal for his distinguished contribution to the development, in theory and practice, of the manufacture of iron and steel. He was elected an Honorary Vice-President of the Institute in May of this year.

Essington Lewis, C.H.

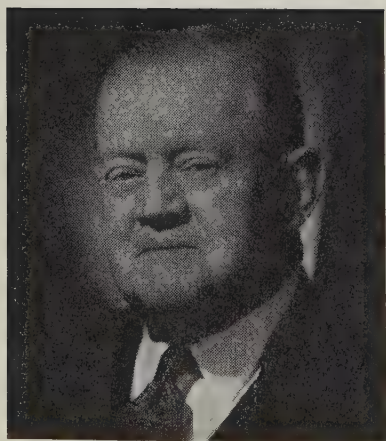
Essington Lewis, C.H., Bessemer medallist and member of The Iron and Steel Institute since 1921, died at his country home near Melbourne on Sunday, 1 October, aged 80.

Born in South Australia, he worked for a time on one of his father's cattle stations before graduating in law from Adelaide university. He then decided on a career in mining and in 1903 began working underground at Broken Hill, having already worked in mines in South Australia and Tasmania during his school holidays. Two years later he gained a diploma from the South Australian School of Mines, and he became assistant manager of a smelting plant at Port Pirie, South Australia, where the Broken Hill Proprietary Company (BHP) was carrying out early experiments in ironmaking.

In 1911 when BHP established a steelworks in Newcastle, New South Wales, Essington Lewis was production engineer for the new works which produced its first steel in 1917. From then on he helped guide the company to its present position as the largest steel producer in the Commonwealth.

He was appointed assistant general manager of BHP in 1920 and general manager in the following year. In 1938 he became chief general manager of BHP and chairman of the Australian government's advisory panel on industrial organization, as well as consultant to the Defence Department. He anticipated the country's need to produce armaments by setting up a shell-making plant at Newcastle, and in 1940 he was appointed Director-General of Munitions, and later of Aircraft Production. It was in recognition of this work that he was made a Companion of Honour in 1943, and in 1944 the Council of The Iron and Steel Institute awarded him the Bessemer Gold Medal for 'his great services in building up the iron and steel industry in Australia'.

In 1950 he became chairman of BHP, and two years later he retired to become deputy chairman, the position he occupied at his death.



Powder Metallurgy Joint Group

Winter meeting 1961

The Winter meeting of the Powder Metallurgy Joint Group of The Iron and Steel Institute and The Institute of Metals will be held on **Thursday and Friday, 7 and 8 December**, at Church House, Great Smith Street, London SW1. The first session, from 2.30 pm to 5 pm on Thursday, will consist of a discussion on papers previously published in *Powder Metallurgy*. The second day will be given to a symposium on sintered high-temperature compounds, the papers for which were published in *Powder Metallurgy* no.8.

Spring meeting 1962

The Spring meeting on Monday and Tuesday, 7 and 8 May, at Church House, will consist of a symposium on sintered low-alloy steel engineering components.

Winter meeting 1962

The programme for the Winter meeting next year is a two-day discussion on 10 and 11 December on non-metallic dispersions in powder metallurgy.

Further details of the Group's activities are available from the Secretary, Powder Metallurgy Joint Group, 17 Belgrave Square, London SW1.

The rolling of iron and steel

The rolling of iron and steel, 1955-1960 which is no.15b in The Institute's Bibliographical Series, has been published, price 30s to members and 40s to others. The two earlier bibliographies under this title covered the period 1920-1954; the closing date of the present one is about the end of 1960.

Because of the change of emphasis in rolling operations, much material has been included on the electrical aspects of rolling mills, on gauge measurement and control, and on automation. There is also a section on the manufacture of seamless tube and on the use of the rolling process for various novel methods of plastic shaping.

Some 2000 references, with abstracts, have been included, and there is a comprehensive index to these, to textbooks, and to the appropriate BISRA reports. Copies are available from the Secretary of The Iron and Steel Institute.

British Nuclear Energy Conference: British Nuclear Energy Society

The following announcement by Sir Leonard Owen, C.B.E., chairman of the British Nuclear Energy Conference (of which The Iron and Steel Institute is a constituent society) appeared in the October issue of the Journal of the BNEC.

On 1 January 1962 the British Nuclear Energy Society will be established in succession to the British Nuclear Energy Conference; the October issue of the Journal of the British Nuclear Energy Conference is the last in its present form and under its present title.

The successful use of nuclear energy demands the application of many divisions of science and technology and a constant interchange of knowledge and experience between those trained primarily in these divisions. It was to provide a channel for this interchange that in 1955 the British Nuclear Energy Conference was established by the Institution of Civil Engineers, the Institution of Mechanical Engineers, the Institution of Electrical Engineers, the Institute of Physics, and the Institution of Chemical Engineers, who were joined later by The Iron and Steel Institute, The Institute of Metals, the Institute of Fuel, and the Joint Panel on Nuclear Marine Propulsion.

The Conference has sought to fill its rôle principally in three ways:

1. By publishing under one cover in its Journal all the more important papers on nuclear energy presented to the constituent societies.
2. By keeping members of the individual societies informed of those meetings of the other societies that are devoted to aspects of nuclear energy, and making such meetings open to them.
3. By sponsoring meetings on nuclear energy organized either for the Conference by the appropriate societies, or, where the subject involves the application of several disciplines, by the Conference itself.

The Board of the Conference feels, however, that the time has now come to provide a central forum for the discussion of nuclear energy and it is for this purpose that the British Nuclear Energy Society has been established. The Institution of Civil Engineers have made their premises in Great George Street, Westminster, available as a meeting place, and a regular programme of papers, lectures, symposia, and informal discussions is being planned.

The Society will (like the Conference) publish a quarterly Journal which in addition to reprinting a wide range of important papers will also contain original papers and discussion on them, information and authoritative scientific and technological comment on developments in nuclear energy throughout the world, and reports on the proceedings of meetings of the Society. The first issue of this Journal will be in January 1962.

Membership of the new Society will be open on application to members of all classes of the constituent societies of British Nuclear Energy Conference (listed above) and to all who satisfy the Board that they are (to quote the Society's constitution) 'actively engaged in the professional, scientific, or technical aspects of the application of nuclear energy and ancillary subjects'.

To ensure continuity, for the first year the affairs of the Society will be managed by the present Board of the British Nuclear Energy Conference, but thereafter the Board will include members elected by and from the general membership of the Society.

An application form for membership is enclosed with this issue of JISI and on completion should be sent to the Secretary of the British Nuclear Energy Conference, 1-7 Great George Street, London SW1. Its prompt return and acceptance will mean that Members will be able to participate from the start in the activities of the new Society.

THE IRON AND STEEL INSTITUTE

New Honorary Vice-President

The President (Sir Charles Goodeve) announced during the opening session of the Special Meeting in New York on 19 October that the Council had elected Dr J. B. Austin (Administrative Vice-President, Research and Technology, United States Steel Corporation), Chairman of the Special Committee for the Meeting, to be an Honorary Vice-President of the Institute. He handed the diploma to Dr Austin who expressed his appreciation.

Autumn General Meeting 1961

The Institute's Autumn General Meeting and a meeting of the Iron and Steel Engineers Group will be held in London from **Wednesday 29 November to Friday 1 December 1961**. The programme was given on pp.77-78 of the September issue of the *Journal*.

Annual General Meeting 1962

The Annual General Meeting will be held in London on **Wednesday and Thursday 2 and 3 May 1962**. The annual dinner for members will be held on the Wednesday evening.

Special meeting in Germany, 1962

As previously announced, by invitation of the Verein deutscher Eisenhüttenleute the Institute will hold a special meeting in Düsseldorf from **Monday 2 July to Sunday 8 July 1962**. The draft programme of the meeting was given on p.191 of the October issue of the *Journal*.

Other meetings

Joint meeting with the Institute of Fuel, Wednesday 13 February 1962
Details on p.191, October issue.

Special meeting in India, 1963
Preliminary notice on p.191, October issue.

Special lectures

As announced in the October issue, lectures on 'The British steel industry and the Common Market' are being delivered by Mr C. R. Wheeler, C.B.E. (*Past President*), President of the British Iron and Steel Federation, and His Excellency Dr E. N. van Kleffens, Head of the Delegation of the High Authority of the European Coal and Steel Community in the United Kingdom, on the evening of **Wednesday 29 November 1961** at the Hoare Memorial Hall, Church House, London SW1. Admission will be by ticket only, application forms for which have been circulated to Members.

IRON AND STEEL ENGINEERS' GROUP

43rd meeting

As previously announced, the 43rd meeting of the Iron and Steel Engineers Group will be held concurrently with the Autumn General Meeting of the Institute on **Friday 1 December** at the Federation of British Industries, Tothill Street, London SW1. A joint paper on energy balance in integrated steelworks will be presented and discussed. The paper will be pre-printed, but will only be available to those ordering the bound volume of the proceedings of the meeting (price £2 2s) which will be published early next year.

Junior Engineers meeting

A meeting of the Junior Engineers will be held in Newport, South Wales, from **Monday 19 February to Thursday 22 February 1962**. A

paper on electrolytic tinning and continuous galvanizing will be presented and discussed, and there will be several works visits. Further details will be announced later.

NEWS OF MEMBERS

Mr **F. H. Alderson** has joined Edgar Allen and Co. Ltd, Sheffield.

Mr **N. S. Angus** has been awarded a Leverhulme Research Grant in respect of a metallurgical and chemical examination of samples of early iron and steel.

Mr **F. T. Bagnall** is now a consultant to Birlec-Efco (Melting) Ltd.

Mr **A. D. Baynes** has joined The North Eastern Iron Refining Co. Ltd, Stillington, Stockton-on-Tees, as chief metallurgist.

Mr **P. R. Belcher** has joined Shell Research Ltd, at the Thornton Research Centre.

Dr **I. S. Brammar** has left Tube Investments Research Laboratories to take up a position with Aeon Laboratories.

Major **W. R. Brown**, D.S.O. (*Honorary Vice-President*) has retired from the board of Davy-Ashmore Ltd. He remains a director of Ashmore, Benson, Pease and Co. Ltd.

Mr **D. Campbell** has been appointed process development officer at the Redbourn works of Richard Thomas and Baldwins Ltd.

Mr **D. F. Campbell** (*Honorary Vice-President*) has retired as chairman of Davy-Ashmore Ltd.

Mr **A. H. Colley** is now a metallurgical assistant at Avesta S.A. (Pty) Ltd.

Mr **C. G. Conway** has been appointed sales manager of Great Lakes Carbon International Ltd.

Mr **J. F. Crittall**, managing director of Crittall Manufacturing Co. Ltd, has been elected chairman of the company.

Mr **G. Curbishley** is now works metallurgist at Rolls-Royce (Sentinel) Ltd, Shrewsbury.

Dipl. Ing. **Otwin Cusoleca** has left Österreichisch-Alpine Montangesellschaft and joined Felten und Guillaume A.G. as a member of the board of directors.

Mr **M. F. Dowding** has been appointed managing director of Davy and United Engineering Co. Ltd.

Mr **G. Fenton** is now with Fosco International Ltd, Birmingham.

Mr **M. A. Fiennes** (*Member of Council*) has been elected chairman of Davy-Ashmore Ltd. He has relinquished his appointment as managing director of Davy and United Engineering Co. Ltd, but remains chairman.

Mr **N. Gripenberg** has been appointed resident manager of Oy Koverhar Ab, a subsidiary of Oy Vuoksenniska Ab, Helsingfors.

Mr **S. C. Guha Maulik**, formerly connected with the Durgapur steel project, has been appointed chief superintendent (iron and steel) of Hindustan Steel Ltd, Bhilai Steel Project, Durgapur (M.P.).

Mr **G. W. Haines** has been appointed area manager for Birmingham and East Midlands, for Wild-Barfield Electric Furnaces Ltd and the Furnace Division of GWB Furnaces Ltd.

Mr **C. W. Hawkes** has left Visco Ltd, to take up a position with Campbell, Gifford and Morton.

Mr **E. J. L. Howard** has left Mather and Platt Ltd, and is in practice as a consulting metallurgist in Macclesfield, Cheshire.

Mr **B. A. Jessop** is now technical secretary to the Steelmaking Division of BISRA.

Mr **K. Koeten** is now commercial director of Hewitt-Robins (Holland) N.V. in Amsterdam.

Mr **R. M. Lamb** has taken a position with Birmid Auto Castings Pty, Ltd, Geelong, Victoria, Australia.

Mr **G. A. Lomas**, managing director and deputy chairman of J. and J. Dyson Ltd, has taken office as president of the Refractories Association of Great Britain.

Mr **J. Mitchell**, C.B.E. (*Past-President*, *Bessemer Medallist*), has been appointed a director of the Lancashire and Corby Steel Manufacturing Co. Ltd, Northants.

Mr **E. R. Perry** is now chief metallurgist at Delaney Gallay Ltd, Cricklewood.

Mr **Lauri Pietiläinen** has been appointed chief metallurgist at Imatra Järnverk.

Mr **J. F. Pratt** has retired from Partridge, Jones and John Paton Ltd.

Dr **E. G. Ramachandran**, formerly assistant director, physical metallurgy division of the National Metallurgical Laboratory, is now professor of metallurgical engineering at the newly established Indian Institute of Technology, Madras.

Mr **R. Rolls** is now a lecturer at the Manchester College of Science and Technology.

Mr **S. Scott** has been elected to the board of the South Durham Steel and Iron Co. Ltd.

Mr **S. Selmer-Olsen** has taken a position with the Tasmanian Electro Metallurgical Co. (Temco), Tasmania, a subsidiary of B.H.P.

Dr **M. G. Snellman** has been appointed resident manager of Imatra Järnverk.

Mr **H. E. N. Stone** is now research and development metallurgist at Metallic Surfaces Research Laboratories, Uxbridge.

Mr **S. H. Walker** has been elected to the board of the South Durham Steel and Iron Co. Ltd.

Obituary

Tom Peach Colclough, C.B.E. (elected 1921, *Bessemer medallist*, *Honorary Vice-President*), of Buckinghamshire, on 22 September. (See obituary, p.308).

A. Morgan Gabe (elected 1936), of Penylan, Cardiff, on 24 February.

Essington Lewis, C.H. (elected 1921, *Bessemer medallist*), of Victoria, Australia, on 1 October. (See obituary, p.308).

Emmanuel A. L. Noel (elected 1959), of Sclessin (Liège), on 7 June.

AFFILIATED LOCAL SOCIETIES

STAFFORDSHIRE IRON AND STEEL INSTITUTE

Officers 1961-62

President E. B. Gibbons; *Senior Vice-President* G. T. Hampton; *Junior Vice-President* L. Harper; *Trustees* P. Jump, H. E. Cookson, W. H. Lewis; *Hon. Auditors* N. S. B. Janes and L. Chater; *Hon. Treasurer* G. E. Lunt; *Secretary* G. Riley; *Members of Council* T. H. Morfey, G. Harrison, A. Meachem, G. B. Forster, M. Lloyd, N. Dean, E. H. Sutton, W. L. Beasley, B. C. Bruce-Gardner, and B. V. Peters; *Members of Council (Past Presidents)* F. V. Wright, L. W. Law, W. H. B. Wesson, A. W. Shore, K. G. Lewis, and K. H. Wright.

EAST MIDLANDS METALLURGICAL SOCIETY

Officers 1961-62

President (1961-63) M. I. McIntyre; *Secretary* H. L. Parker; *Treasurer* P. A. Blackwell; *Committee* N. Angus, H. E. Gresham, J. Hicklin, Dr E. Holmes, Dr J. A. Hoskins, G. T. Jackson.

SWANSEA AND DISTRICT METALLURGICAL SOCIETY

Officers 1961-62

President P. Mackay; Vice-Presidents E. McVicar, D. J. D. Unwin; Hon. Treasurer L. A. S. Perrett; Hon. Secretaries P. E. Morgan, R. L. Williams; Members of Council Dr C. S. Ball, C. H. Cuniffe, S. M. Ferris, B. V. Guellard, R. H. Humphreys, J. H. Lamb, J. D. Richards, Prof. A. R. E. Singer.

LEEDS METALLURGICAL SOCIETY

Officers 1961-62

President E. V. Dewhurst; Hon. Secretary Dr P. R. Beeley; Hon. Treasurer K. Hill (Past President); Vice-Presidents Dr P. Feltham, Dr. H. W. Raynor; Members of Council Dr E. Simister (Past President), W. L. Bolton (Past President), L. H. Wadsworth, B. H. Wilby, F. Smith, Dr P. T. Gilbert, P. M. Kelly.

LINCOLNSHIRE IRON AND STEEL INSTITUTE

Lincolnshire Ironmasters' Award

Members of the Lincolnshire Iron and Steel Institute under 31 years of age are reminded that the closing date for the submission of papers for the Award is 31 December. The Award carries a cash prize of £25, and further details are available from Mr R. H. Siddons, ironworks engineer, The Appleby-Frodingham Steel Company, Scunthorpe, Lines.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

A BISRA research section renamed

In recognition of the steady growth in the scope of its activities over recent years, the Computer Applications Section of BISRA's Operational Research Department has now been renamed the Systems Evaluation Section.

The duties of the new section, which will be headed by Mr D. H. Kelley, B.Sc., will be to carry out operational research investigations into the automation of large-scale systems.

The immediate programme will be to study the automatic production planning and scheduling of various kinds of steelworks, and to investigate the information requirements of steelworks management.

The services to BISRA members which were previously supplied by the Computer Applications Section and which included operation of the Association's Pegasus computer, advice on the uses of digital computers in steelworks offices, and the training of Pegasus programmers, will be continued unchanged.

EDUCATION

Course on chemical applications of diffraction methods

The Bradford Institute of Technology has announced a two-day course on chemical applications of diffraction methods, to be held at the Institute on Friday and Saturday 24 and 25 November. It is thought that the sections on X-ray powder methods and electron diffraction will be of particular interest to metallurgists. Details and registration forms are available from the Registrar, Institute of Technology, Bradford 7.

Refresher course for works and plant engineers

The latest comprehensive refresher course for works and plant engineers, organized by the Institution of Plant Engineers, has begun at the Institution of Engineers and Shipbuilders, Elmbank Crescent, Glasgow. The course consists of 18 weekly lectures, on Wednesday evenings, the first of which was given on 1 November.

The course, which has been sponsored by Sir Andrew McCance, chairman of Colvilles Ltd and chairman of the board of governors of the Royal College of Science and Technology, Glasgow, is designed to encourage the most

effective use of existing knowledge and promote the application of up-to-date techniques in works engineering practice over a broad field.

The fee for the course is 4 gns, and full details are available from the Secretary to the Refresher Course, 39 Elmbank Crescent, Glasgow C2.

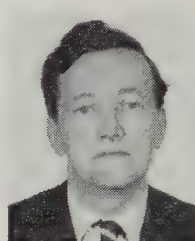
Engineering materials: postgraduate course

A postgraduate course of 13 evening lectures on Mondays from 7 pm to 9 pm begins on 13 November at the Northampton College of Advanced Technology, St John Street, London EC1. Full details are available from the college.

CONTRIBUTORS TO THE JOURNAL



J. Taylor



P. A. Young

J. Taylor, M.Sc., Ph.D. - Principal lecturer in metallurgy, Royal College of Science and Technology, Glasgow.

John Taylor graduated with first-class honours in chemistry at the former Armstrong College of Durham University in 1926. He then carried out postgraduate research in fuel technology, at Imperial College, London, under Professor Bone, and in physical chemistry at the Technische Hochschule, Danzig, under Professor von Wartenberg. After some years in the Coal Survey Laboratory and in the coke-oven industry, he joined the former research section of the British Iron and Steel Federation (now BISRA), as field tests officer on blast-furnace research. During the war he worked with the Ministry of Supply on carburization from the point of view of armour plate. He joined the Royal Technical College, Glasgow, in 1945. Dr Taylor has been a member of The Iron and Steel Institute since 1946.

E. W. Voice, B.Sc., A.Inst.P. - Assistant director, head of Ironmaking Division and head of Chemistry Department, British Iron and Steel Research Association.

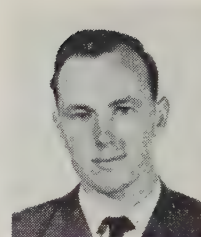


Ernest Wallace Voice was born in London, educated at Latymer Upper School, Hammersmith, and graduated in physics from London University. In 1930 he joined the Gas Light and Coke Company and worked on the domestic utilization of town's gas at their research laboratories at Watson House. During the war years he was seconded to the Ministry of Supply to work on chemical warfare at Porton, near Salisbury.

After the war he joined the Ironmaking Division of BISRA and concentrated on the field trials activities on sintering and the blast-furnace. In 1952 he joined the National Coal Board as acting director of the Mining Research Establishment but returned to BISRA as head of the Ironmaking Division in 1954. He was appointed head of the Chemistry Department in 1956 and assistant director of BISRA in 1959.

P. A. Young, M.A., Ph.D. - Research and Development Division, Head Wrightson and Co. Ltd.

P. A. Young was educated at the Royal Naval Engineering College, and Cambridge Uni-



P. Butterfield



M. S. Rhodes

versity, where he read natural sciences. At Cambridge he held the Elmore Research Fellowship in extraction metallurgy and his main interests were in the non-ferrous field.

For the last four years he has been general manager of the central research and development division of the Head Wrightson group of companies, and he has become particularly interested in the application of quantitative 'chemical engineering' methods to the iron and steel industry.

P. Butterfield, B.A. - Research and Development Division, Head Wrightson and Co. Ltd. P. Butterfield was born in Middlesbrough in 1937. After attending Acklam Hall grammar school he studied mathematics at Trinity college, Cambridge, from 1955 to 1958. Since graduation he has worked for Head Wrightson and Co. Ltd, Thornaby-on-Tees in the research and development division. His particular concerns have been heat transfer, fluid flow, and general computer applications.

M. S. Rhodes, B.Sc. - Research and Development Department, United Steel Companies Ltd.

M. S. Rhodes graduated from Birmingham University in 1954 with honours in mathematical physics. For the next four years he worked on model design and test result analysis for the Bristol Aeroplane Co. Ltd. In 1958 he was appointed research mathematician in the mathematics section of the Research and Development Department of the United Steel Companies Ltd, which position he still holds. He is engaged upon research work of a mathematical nature with special reference to heat transfer as encountered in the iron and steel industry. This work mostly involves calculations which are best tackled with the help of an electronic digital computer.

H. B. Bell, B.Sc., Ph.D., A.R.C.S., F.I.M. - Royal College of Science and Technology, Glasgow.

Dr H. B. Bell was educated at Greenock High School and then at the Royal College of Science and Technology and Glasgow University. He gained his B.Sc. with first-class honours in metallurgy and also an Associateship of Royal College. After graduation he was appointed Research Assistant and afterwards became Union Carbide Research Fellow in the Metallurgy Department of the R.C.S.T. He gained his Ph.D. for a thesis concerned with slag-metal equilibria. Dr Bell was appointed lecturer in the metallurgy department of the R.C.S.T. in 1953 and he has been mainly concerned with extraction metallurgy and research into physical chemistry of iron and steel production. He was elected a Fellow of The Institution of Metallurgists in 1959. He has published several papers on extraction metallurgy. From 1939 to 1946 he was assistant metallurgist at Scotts Shipbuilding and Engineering Co., Ltd at Greenock.

NEWS OF SCIENCE AND INDUSTRY

The master cutler

Mr Gerard Young, J.P., Chairman of Tempered Group Ltd, is the 326th Master Cutler. Mr Young is a member of the Institute of Mechanical Engineers and a founder-member of the Coil Spring Federation.

British Coke Research Association: appointment of chairman

The managing director (mining and carbonization) of The United Steel Companies Ltd,

Lt-Col. P. F. Benton Jones has been appointed chairman of council of the British Coke Research Association.

Company news

Davy-AEI Automation is a jointly owned company, formerly AEI-United Steelworks Automation Unit, which will apply automation to the processing of steel and non-ferrous metals.

International Systems Control Ltd., of Wembley, have announced that Thompson Ramo Wooldridge Inc. of Los Angeles, which with GEC Ltd of England is jointly interested in ISC Ltd, have received an order from the Great Lakes Steel Division of the National Steel Corporation for a computer system to control the world's largest basic oxygen steel furnace plant at Detroit. The computer will take into account the characteristics of raw material and furnace and the specification of the end product.

Materials Handling Division of Fisher and Ludlow Ltd, have modernized the storage system of the rolling mills and workshops of the Margam and Port Talbot works of The Steel Company of Wales. Palletization, making use of vertical space, has increased the capacity of existing stores buildings by about 80%, and thereby dispensed with the need for a proposed new building which would have cost about £250,000.

Contract news

Dorman Long (Steel) has now placed the first major orders, totalling £2.85 m., in connexion with the present state of their development programme. A high-lift slabbing and blooming mill for Lackenby, at £1,300,000, will be supplied by *Davy United*. Soaking pits valued at about £700,000 will be supplied by *Priest Furnaces*. An order worth about £450,000 has been placed with *Associated Electrical Industries* for the blooming and slabbing mill drive. Ingot stripping and soaking pit cranes valued at about £400,000 will be supplied by *Wellman Smith Owen Engineering*.

Stothert and Pitt have received a £400,000 contract from Stanton Ironworks Company for a complete slag preparation plant, with a designed capacity of 200 tons/h.

Model of Iscon project

Davy and United Engineering Co. Ltd., recently showed in London a $\frac{1}{16}$ in./ft model of the four main areas of the new Durgapur steel-works in West Bengal for which the company has been responsible as main contractor. The model is to be presented to Hindustan Steel Ltd for display at the forthcoming Indian Industries Fair in New Delhi. Hindustan Steel Ltd will run the three new state steelplants in India on behalf of the Indian Government.

CHANGES OF ADDRESS AND TITLE

The Research Director of the Rollmakers Association is now at Windsor House, Temple Row, Birmingham 2.

Kellogg International Corporation have moved to Kellogg House, 62-72 Chiltern Street, Baker Street, London W1.

Visco Ltd is the new name of the Visco Engineering Co. Ltd.

The American Institute of Mining, Metallurgical and Petroleum Engineers Incorporated has moved to 345 East 47th Street, New York 17, NY, USA.

Singhalest Equipment Ltd have transferred their Blyth depot to 29 Carlton Street, Blyth, Northumberland.

Singhalest Engineering Ltd have moved to 72-76 Clun Street, Sheffield 4.

Norton Grinding Wheel Co. Ltd of Welwyn Garden City, Herts., announce that the address of their Manchester office and warehouse is now Wharf Road, Sale, Cheshire.

Optoshield Ltd, 146 Clerkenwell Road, London EC1, have asked customers to continue to send orders to the sales and head offices at this address, although they are now

transferring all production departments to new accommodation at Watford.

Department of Industrial and Scientific Research headquarters are now at State House, High Holborn, London WC1.

W. S. Atkins and Partners have moved to Arlbee House, Greyfriars Place, Cardiff.

Polygram Casting Co. Ltd have moved to Shernfold Park, Frant, Tunbridge Wells, Kent.

INDUSTRIAL PUBLICATIONS RECEIVED

Efco Shaker Hearth Furnaces gives details of standard and junior furnaces of this type.

In the melting pot, a leaflet issued by the Morgan Crucible Co. Ltd, introduces a new basin tilter.

Fifty blast furnaces is the third edition of a brochure illustrating blast-furnace plant built by Ashmore, Benson, Pease and Co. Ltd.

Resistance welding electrode materials describes a range of rough-machined seam-welding blanks, available in metric sizes, from Johnson, Matthey and Co. Ltd.

Alloys 'V L55' and 'V L55(M)' in the production of S.G. iron, a booklet from Union Carbide Ltd, is a guide to the use of these alloys.

'Holmes-Connesville Positive Air Blowers type RBS' is the title of the latest leaflet issued by W. C. Holmes and Co. Ltd.

Plastic-coated corrosion-resistant steel sheets for cladding buildings are described in a leaflet from *Dorman, Long and Co. Ltd*.

CORRIGENDA

Monsieur Daniel Petit has pointed out the following errors in his paper 'The high-temperature Cowper stove' published in the September issue of the *Journal* (pp.33-46). p.34, col.1, paragraph headed 'Temperature of cold blast'. The section from the 3rd sentence of this paragraph beginning 'In view of the long life . . .', to the end of the 7th line in col.2, should follow at the end of the first sentence at the top of col.1.

p.45. Calculation for Kp at the bottom of col.2, should read

$$Kp = \frac{0.75}{\frac{1}{25.5} + \frac{1}{2 \times 17.9}} = 11.17 \text{ cal.m}^2/\text{h}^\circ\text{C}$$

ADDENDUM

In the June 1961 issue of the *Journal*, in the discussion on martensite (p.176), Professor R. F. Mehl referred to work on the effect of prior deformation on the properties of quenched steel, reported by Lips and van Zuilen in a paper in *Metal Progress* in 1954. Mr Richard F. Harvey has drawn the Editor's attention to a paper published by him in *Iron Age*, 27 December 1951, dealing with the method of working steels in the metastable austenitic condition. The method of working steels above the M_s temperature has been designated 'Marworking' and is covered by US patent 2717846, issued to Mr Harvey on 13 September 1955.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Symposium on nuclear electronics

The Institution of Electrical Engineers is holding a symposium on nuclear electronics at its offices, Savoy Place, London WC2, on Thursday 30 November-Friday 1 December 1961. The symposium, which has been arranged in consultation with the International Atomic Energy Agency, will hear and discuss reports on the material presented at the conference on nuclear electronics arranged by the IAEA in Belgrade last May.

The symposium will consist of three sessions, dealing respectively with radiation detectors, electronic circuits and techniques, and radiation monitors and instruments. The first session begins at 5 pm on 30 November.

The registration fee to members of The Iron and Steel Institute (as a constituent member of the British Nuclear Energy Conference) is £1.

Registration forms and further information are available from the secretary of The Institution of Electrical Engineers at the above address.

Symposium on vacuum science and technology

The Institute of Physics and the Physical Society announces that it will be holding a one-day symposium on 'Some aspects of vacuum science and technology', at Imperial College of Science and Technology, London, on 5 January 1962.

The scope of the symposium will be: (a) continuously exhausted bakeable vacuum apparatus for pressures below 10^{-9} mm Hg, and (b) the controlled deposition of evaporated film.

Further details and application forms are available from the Administration Assistant, The Institute of Physics and The Physical Society, 47 Belgrave Square, London SW1.

Ferroalloy industry in India

The National Metallurgical Laboratory, Jamshedpur, India, has announced a symposium to be held early in February 1962. The general scope of the symposium will be to survey the raw materials available in India, particularly with regard to metallurgical quality and availability; beneficiation of raw materials; evaluation of various production processes applicable to Indian conditions; basic physico-chemical and thermodynamic principles involved; production technology for laboratory, pilot plant, and industrial production; utilization of by-products; standard specifications for ferroalloys and raw materials, and finally a review of the present situation and future possibilities of the ferroalloy industry in India.

Papers for presentation at the symposium are being invited, and further details are available from Dr B. R. Nijhawan, director of the Laboratory.

International Coal Preparation Congress

The fourth congress organized jointly by the National Coal Board and the Coal Preparation Plant Association will be held in Harrogate from 28 May to 1 June 1962. Further details are available from the Congress secretary, National Coal Board, Hobart House, Grosvenor Place, London SW1.

DIARY

7-10 Nov. AMERICAN NUCLEAR SOCIETY - Winter Meeting - Chicago, Illinois, USA.

8-10 Nov. INSTITUTION OF ELECTRICAL ENGINEERS and BRITISH NATIONAL COMMITTEE ON NON-DESTRUCTIVE TESTING - Conference on non-destructive testing in electrical engineering - Institution of Electrical Engineers, Savoy Place, London WC2.

9 Nov. STAFFORDSHIRE IRON AND STEEL INSTITUTE - Presidential address by Mr E. B. Gibbons - Training College, Stewarts and Lloyds Ltd, Bilston, Staffs., 7.30 pm.

13-16 Nov. NATIONAL MAINTENANCE CONFERENCE and EXHIBITION - Central Hall, Westminster, London SW1.

13-18 Nov. 2ND ENGINEERING MATERIALS and DESIGN EXHIBITION and INTERNATIONAL FACTORY EQUIPMENT EXHIBITION - Earls Court, London.

14 Nov. WEST OF ENGLAND METALLURGICAL SOCIETY - Discussion on teaching metallurgy to metallurgists and engineers - Bristol College of Technology, Bristol 7.

14-17 Nov. SYMPOSIUM ON CORROSION IN NUCLEAR TECHNOLOGY - Paris.

15-29 Nov. BUILDING EXHIBITION - Olympia, London.

16 Nov. WEST OF SCOTLAND IRON AND STEEL INSTITUTE - Junior members' night, papers on marking, cutting, and testing of steel - 39 Elmbank Crescent, Glasgow, 6.45 pm.

- 16 Nov.** EBBW VALE METALLURGICAL SOCIETY - Joint meeting with ISI Engineers Group, lecture, 'Automatic controls in the steel industry', by R. Reid - RTB Welfare Hall, Ebbw Vale, 7.30 pm.
- 22 Nov.** MANCHESTER METALLURGICAL SOCIETY - Lecture, 'Metallurgy of the rarer metals', by Dr J. C. Chaston - Literary and Philosophical Society, 36 George Street, Manchester 1 6.30 pm.
- 22-27 Nov.** CONFERENCE AND EXHIBITION ON AUTOMATION AND INSTRUMENTATION - Milan.
- 27 Nov.-1 Dec.** INTERNATIONAL AUTOMATION EXHIBITION - New York.
- 28 Nov.** JOINT PANEL ON NUCLEAR MARINE PROPULSION - Lecture, 'High temperature gas-cooled reactors for marine propulsion', by J. E. Richards - 76 Mark Lane, London EC3, 5.30 pm.

- 29 Nov.-30 Nov.-1 Dec.** IRON AND STEEL INSTITUTE - INSTITUTION OF ELECTRICAL ENGINEERS AND BRITISH NUCLEAR ENERGY CONFERENCE - Symposium on nuclear electronics - Institution of Electrical Engineers, Savoy Place, London WC2.
- 1 Dec.** Autumn general meeting on 'The future of ironmaking in the blast-furnace' and other topics - FBI, Tothill Street, London SW1, and offices of Institute, 4 Grosvenor Gardens, London SW1.
- 1 Dec.** SOCIETY FOR ANALYTICAL CHEMISTRY, NORTH OF ENGLAND SECTION - Lecture, 'Design and construction of laboratories', by R. R. Young and P. J. Harrington - Manchester Literary and Philosophical Society, 36 George Street, Manchester 1, 2 pm.
- 5 Dec.** NEWPORT AND DISTRICT METALLURGICAL SOCIETY - Film, 'O for

- 5 Dec.** oxygen' - Whitehead Institute, Cardiff Road, Newport, 7 pm.
- 5 Dec.** INSTITUTION OF ELECTRICAL ENGINEERS - Lecture, 'Domains and domain patterns', by Prof. L. F. Bates - Institution of Electrical Engineers, Savoy Place, London WC2, 5.30 pm.
- 5 Dec.** LEEDS METALLURGICAL SOCIETY - Lecture, 'Dislocations', by Prof. J. Nutting - University Staff House, University Road, Leeds, 6.30 pm.
- 6 Dec.** MANCHESTER METALLURGICAL SOCIETY - Lecture, 'The newer magnetic materials', by K. Hoselitz - Manchester Literary and Philosophical Society, 36 George Street, Manchester 1, 6.30 pm.
- 7 Dec.** EAST MIDLANDS METALLURGICAL SOCIETY - Lecture, 'Metallurgy of tungsten', by D. J. Jones - Dept. of Metallurgy, Nottingham University, 7.30 pm.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 194 of the October 1961 issue of the *Journal*.

When ordering please, quote the number in bold type.

The heterogeneity of killed steel ingots. (From French.) KOHN, A., *Coulée de l'Acier*, 1958 (Cahiers du Cessid), (1), part 3, pp.1-52. (£15) **[1436]**

Electrical resistance heating for the treatment of steel. (From Italian.) STRICH, W., IV Congrès International d'Electrothermie, Stresa 25-29 May 1959. **[1925]**

The department of economic production control in the service of top management. I. Functions and position of production control within the works. (From German.) SCHÜTTE, W., *Stahl Eisen*, 1960, 80, 27 Oct., pp.1551-1553. (£2 10s. 0d.) **[1974]**

The use of oxygen in a 100-ton Maerz-Boelens furnace at Hörde. (From German.) KRABIELL, H.-J., and KNACKSTEDT, E., *Stahl Eisen*, 1960, 80, 27 Oct., pp.1492-1496. (£4) **[1975]**

The new Bremen iron and steelworks for the Klöckner-Werke AG in the North Sea coastal region. II. (Part I is BISI 2011). (From German.) HEEMMEYER, W., and ASBECK, W., *Stahl Eisen*, 1960, 80, 10 Nov., pp.1711-1727. (£7 5s. 0d.) **[1996]**

BISI 2026-2028, 2135

Four papers presented at the centenary celebrations of the Verein deutscher Eisenhüttenleute, Düsseldorf, 3-4 November 1960 (JISI abstr. 1961, July 337a) *Stahl Eisen*, 1960, 80, 8 Dec.

The development of metallurgical processes and production methods 1860-1960 (with bibliography: 113 refs). (From German.) SPRINGER, F. A., pages 1838-1851. **[2026]**

Examples from the historical development of steel shaping. (From German.) OCHSEL, W., pp.1852-1863. **[2027]**

The function of steel in technical developments in the last 100 years. (From German.) KALLEN, H., pp.1864-1877. **[2028]**

The development of technology and its influence on the cost pattern of iron and steel production. (From German.) RHEINLANDER, P., pp.1878-1890. **[2035]**

Price: £6 each or £20 for the set of four.

Investigation of friction in the hot rolling of steel. (From Russian.) PAVLOV, I. M., and KUPRIN, M. I., *Technologicheskie protsessy obrabotki stali i splovov* (Sbornik 33, Moskovskii ... Institut Satli imeni I. V. Stalina) [Technological processes of shaping steel and alloys (Collection 33, 'I. V. Stalin' Moscow Institute of Steel)] Moscow, Metallurgizdat, 1955, pp.154-192. (£10) **[2050]**

Recent results obtained with the Quantovac in the analysis of steels. (From French.) BARRY, W. H., and CARROL, J. M., *Rev. Univ. Mines*, 1959, 15, May, pp.281-289. (£6) **[2087]**

Welding grey and nodular cast irons. (From German.) PUSCHNER, M., and SUCHANEK, G.,

Technica, 1960, 9, 7 Oct., pp.1295-1298. (£4) **[2116]**

Influence of the initial state of a metal on changes in crystalline structure during fatigue at high temperatures. (From French.) FOUQUET, J. DE., *Rev. Mét. Mém. Sci.*, 1960, 57, March, pp.232-240. (£5 10s. 0d.) **[2122]**

Theoretical discussion of the influence of ferromagnetic coercive forces of spheroidal inclusions which are small as compared with the thickness of the Bloch walls. (From German.) SCHWABE, E., *Annalen der Physik*, 1952, 11, (2-3), pp.99-112. (£3 10s. 0d.) **[2139]**

Measurements in electric sheet in the laboratory and in production. (From German.) KRUG, W., *ETZ-A*, 1959, 80, 1 Sept., pp.593-599. (£4 5s. 0d.) **[2156]**

Surface conditioning of ingots and billets. (From Swedish.) KIHLENGREN, G., *Jernkont. Ann.*, 1956, 140, (4), pp.314-344. (£6 15s. 0d.) **[2159]**

Determination of the design and size of hot blast stoves. (From German.) HEILIGENSTADT, W., *Stahl Eisen*, 1951, 71, 24 May, pp.568-575. (£5 10s. 0d.) **[2160]**

The morphology of oxidation films. (From French.) PAIDASSI, J., Third colloquium on metallurgy, *Corrosion*, 1959, pp.71-110. (CEA report no. 1523). (£8 5s. 0d.) **[2180]**

Absorption and evolution of hydrogen in iron at high temperatures. (From Swedish.) PIHLSTRAND, F., *Jernkont. Ann.*, 1937, 121, (5), pp.219-231. (£3) **[2224]**

Hydraulic transport of coal. (From French.) AUBATHIER, P., Conferencia Mundial de la Energia, World Power Conference, Paper III A/1. Madrid 59 June 1960. (£4) **[2228]**

The pressure drop in the inlet zone of pneumatic transport systems. (From German.) JUNG, R., *Forschung auf dem Gebiete des Ingenieurwesens*, 1958, 24, (2), pp.50-58. (£5 10s. 0d.) **[2246]**

The problem of skin rupture in the continuous casting of steel. (From French.) GOUZOU, J., and ZAEYTYDT, J., *Rev. Univ. Mines*, 1961, (3), pp.110-134. (£10) **[2266]**

Investigation of vibro-insulation of the foundations of drop hammers under production conditions. (From Russian.) SHCHEGLOV, V. F., and KURIN, V. V., *Kuznechno-Shtampov.*, 1960, 2, Sept., pp.21-26. (£3 15s. 0d.) **[2287]**

Vibro-insulation of drop hammers at the Taganrog Combine Works. (From Russian.) BEZZUBYI, G. I., *Kuznechno-Shtampov.*, 1960, 2, Sept., pp.26-33. (£4) **[2288]**

The use of analogue or digital computers in solving heavy-current problems. II. Transients in a three-phase induction motor. (From Dutch.) BLOM, J. F., *De Ingenieur*, 1960, 17 June, (25), E.42-E.50. (£3 15s. 0d.) **[2297]**

Effect of preliminary annealing in the recovery range on the result of recrystallization annealing of deep-drawing sheets. (From German.) O'DONE, G., and BERRUTI, V., *Stahl Eisen*, 1960, 80, 21 July, pp.1018-1023. (£3 5s. 0d.) **[2307]**

Wear of chrome-magnesite bricks in open-hearth furnace roofs. (From German.)

KIENOW, S., *Arch. Eisenhüt.*, 1961, 32, Feb., pp.77-87. (£6 10s. 0d.) **[2309]**

Investigation of welding materials and steels for tendency to weld seam cracking. (From German.) WERTHEBACH, P., *Stahl Eisen*, 1953, 73, 15 Jan., pp.84-91. (£5) **[2312]**

Comparison of the mechanical properties of drawn steel wires after patenting carried out in lead baths, salt baths, and in air. (From German.) EISENHUTH, C., and KRAUTMACHER, H., *Stahl Eisen*, 1952, 72, 25 Sept., pp.1217-1221. (£3 5s. 0d.) **[2313]**

Assessing performance and consumption data in iron and steelworks. (From German.) PLUGGE, H.-H., *Stahl Eisen*, 1961, 81, 30 March, pp.408-421. (£8 10s. 0d.) **[2326]**

The Kaldor process at Sollac. (From French.) COLMANT, R. et al., *Rev. Mét.*, 1961, 58, Jan., pp.39-43. (£2 10s. 0d.) **[2327]**

The equal distribution of blast at the tuyeres of a blast-furnace (with discussion). (From French.) TAVARD, *Centre Doc. Sider. Circ.*, 1960, 17, Feb., pp.429-436. (£2 10s. 0d.) **[2328]**

The solubility of basic converter slags in citric acid. (From French.) DECKER, A. et al., *Rev. Univ. Mines*, 1956, 9th series, 12, Dec., pp.652-660. (£3 5s. 0d.) **[2330]**

The cost of changing rolls of stands, changing roll passes or guides, and trial rolling. (From German.) WEISENFELD, H. et al., *Stahl Eisen*, 1961, 81, 25 May, pp.725-728. (£3) **[2331]**

The influence of the flux on the properties of welded joints in high-strength steel. (From Russian.) LYUBAVSKY, K. V. et al., *Svar. Proizv.*, 1959, (2), pp.23-25. (£2 5s. 0d.) **[2348]**

On a new dust measuring method. (From German.) WINKEL, A., *Staub*, 1959, 19, 1 July, pp.253-255. (£2 5s. 0d.) **[2353]**

Conversion and processing cost analysis in iron and steelworks as a guide to rationalization. (From German.) POPPE, K. E., *Stahl Eisen*, 1955, 75, 19 May, pp.633-640. (£5 10s.) **[2355]**

Denitrogenization of molten steel with titanium under production conditions. (From Russian.) GUREVICH, YU. G., *Izvest. VUZ Chernaya Met.*, 1961, (5), pp.58-67. (£4 5s. 0d.) **[2359]**

Experiments on the melting in electric furnaces and in open-hearth furnaces of ferrous material obtained by direct reduction (with discussion). (From Italian.) MASI, O., and CANIZZO, P., *Met. Ital.*, 1961, 53, Jan., pp.1-16. (£6 5s. 0d.) **[2360]**

Gas removal from arc furnaces without covers. (From German.) SEM, M., *Rader Rund.*, 1961, (3), June, pp.607-615. (£4 5s. 0d.) **[2368]**

The heating of large ingots in regenerative soaking pits. (From Russian.) TAITIS, N. YU., et al., *Izvest. VUZ Chern. Met.*, 1960, (8), pp.160-166. (£4 10s. 0d.) **[2391]**

The effect of aluminium nitride on the forgeability of steel. (From French.) BASTIEN, P., and PORTEVIN, P., *Comptes Rendus des Séances de l'Académie des Sciences*, 1960, 21 Nov., pp.2347-2349. (£2 5s. 0d.) **[2392]**

ABSTRACTS OF CURRENT LITERATURE *Iron and Steel Manufacture and Related Subjects* AND BOOK NOTICES

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ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast-furnace refractories F. H. Aldred and N. W. Hinchliffe (*JISI*, 1961, 199, Nov., 241-247) [This issue].

Fuel additions and modifications in the blast-furnace H. B. Bell and J. Taylor (*JISI*, 1961, 199, Nov., 272-285) [This issue].

Increase in productivity of blast-furnaces operating on mixed ore burdens J. Boland (*JISI*, 1961, 199, Nov., 253-258) [This issue].

Thermal balance of the iron blast-furnace H. B. Bell and J. Taylor (*JISI*, 1961, 199, Nov., 285-287) [This issue].

Hot blast stoves J. Schofield, P. Butterfield, and P. A. Young (*JISI*, 1961, 199, Nov., 229-240) [This issue].

Stove design and performance E. W. Voice (*JISI*, 1961, 199, Nov., 248-253) [This issue].

PRODUCTION OF STEEL

Methods of manufacturing hydrogen for metallurgical purposes C. Ericsson (*Jernkont. Tek. Rad.*, 1960, 20, (258), 581-640).

A visit to the United steelworks at Kladno H. G. Cordero (*Metal Bull.*, 1960, no.4536, 13-14).

China's iron and steel works. II. Paotow (*Met. Bull.*, 1961, 49, Feb. 24, i-iv).

Development of the steel plant at Donawitz since 1945 F. Narbeshuber (*Berg. Hütten Monatsh.*, 1960, 105, Nov., 323-331).

A growing Chinese steelworks (*Met. Bull.*, 1961, 49, March 14, i) Three illustrations of the Hofei steelworks in Anhwei province are presented.—S.H.-S.

A tuyere for blowing powdered materials into molten metal Z. M. Kudryavtseva (*Stal*, 1961, (5), 464-467) A design is shown with the computations needed. It has an easily replaceable nozzle and can operate at high outlet velocities (> 200 m/sec).

Calculation of converter utilization values of basic Bessemer converters in a steelworks G. Bozza (*Met. Ital.*, 1961, 53, (3), 85-94) [In Italian] A method of calculation is described which takes into account the many variable factors. It indicates that basic Bessemer steelworks is best utilized when (*m* converters being

required to operate simultaneously) the plant consists of $m \times 3$ converters and tapping is at intervals of $\theta \leq T/m$.

The basic Bessemer steelworks of HADIR (*Dema Nachr.*, 1960, (160), 15-22).

Presentation of the basic Bessemer process M. Gombert (*The Thomas Steelworks, IRSID, Les Cahiers du Cessid*, 1959, (5), pp.23) The historical development, and characteristics of the Thomas process, and the main properties of Thomas steel are described, and some recent improvements and possible lines of development of the process are outlined.

Disequilibrium in the concentration adjustment between metal and slag in the basic converter T. Kootz and H. J. Ueberhorst (*Stahl Eisen*, 1961, 81, Feb. 16, 239-248) The authors studied the effect of high levels of SiO_2 , MnO , MgO , Al_2O_3 , TiO_2 , and CaF_2 in the slag on the final composition of the iron bath. The results are discussed in detail. SiO_2 , and to a lesser extent MgO , have a bad effect on dephosphorization, they increase the oxygen level of the iron, increase Mn slagging, and reduce desulphurization.—T.G.

The converter M. Tavard (*The Thomas Steelworks, IRSID, Les Cahiers du Cessid*, 1959, (5), pp.58) The design of the shell, mechanical equipment, lining, and bottom of the Thomas converter are described, and its equipment and productive capacity outlined. Some data on the lining and bottom of the acid Bessemer converter are given in an appendix (22 refs).

The manufacture of basic Bessemer steel (study of a classical operation) P. Boutonnet (*Converter Steels, IRSID, Les Cahiers du Cessid*, 1959, (41), pp.43) The stages of manufacture are followed from the desulphurization of the pig iron to the casting of the steel, with a further section on the manufacture of various grades of steel in the Thomas converter (27 refs).

The blowing operation in the basic Bessemer converter P. Leroy (*The Thomas Steelworks, IRSID, Les Cahiers du Cessid*, 1959, (5), pp.46) Factors influencing blowing and its duration, and the mechanisms of bath movements are discussed (26 refs).

Thermal balance of a basic Bessemer con-

verter J. Givaudon (*The Thomas Steelworks, IRSID, Les Cahiers du Cessid*, 1959, (5), pp.15) Calculation of the thermal balance is discussed, with a section on blowing with oxygen-enriched blast.

Basic Bessemer steel with a low content of metalloids. Part I. General considerations G. Husson (*Converter Steels, IRSID, Les Cahiers du Cessid*, 1959, (41), pp.19) Characteristics in which Thomas steel is considered to be inferior to open hearth steel are examined, and methods of producing improved material, particularly with regard to N and P contents and standardization of quality are discussed (21 refs). **Part 2. Manufacture** P. Leroy (pp.161) Methods of producing Thomas steel low in S, P, and N are discussed, the use of various blast mixtures is considered and a brief review is given of the LD, Kaldo, Rotor, and OLP processes (107 refs).

Adjusting the melting process of new steel types in oxygen-blown converters S. T. Zaikov, P. Ya. Kravtsov, and S. I. Lifshits (*Metallurg*, 1960, (8), 15) [In Russian] Certain types of steel for special purposes are melted in oxygen-blown converters, for example T steel (telegraph wire) KSt2, KSt3, KStO, SvO8 for tubes, etc. In SvO8A steel S and P contents do not exceed 0.03%. The production of low P steel does not present undue difficulties, and from a pig iron with 0.05%S it is possible to obtain a steel with less than 0.03%S melting with two slags and additions of feldspar at the rate of 2 kg/t of metal. The two-slag process increases the duration of the melt by 15-20% and reduces the metal yield by 0.7 to 1.2%.

The reactions taking place during top blowing of oxygen in rotary vessels. II P. E. Hardt, G. Vocke, and H. Schenck (*Stahl Eisen*, 1961, 81, March 2, 311-324) The object of the investigation was to find a steelmaking process that produces a steel of the quality of OH steels from phosphorus-rich pig iron at the costs and output which are similar to those of the conventional basic converter steels. As the P is slagged before the decarburization period is completed the blowing time depends merely on the decarburization rate. And that in turn is higher in ellipsoidal vessels than in cylindrical vessels. This difference increases with increasing oxygen enrichment. The other reactions involved are also studied and the mechanisms acting are discussed. The report is followed by a discussion.—T.G.

New processes for the conversion of iron to steel by the use of oxygen R. Colmant (*Converter Steels, IRSID, Les Cahiers du Cessid*, 1959, (41), pp.55).

A revolution in steel [L. Dat Voest and Donawitz] (*Economist*, 1960, May 21, 771-773).

Experiences gained with LD-steel in wire manufacture E. Foggy and O. Kramer (*Berg. Hütten. Monatsh.*, 1960, 105, Nov., 261-268). Advantages of LD steel over OH and basic Bessemer steel for wire-drawing and manufacture are discussed. Increased output, low die wear, and elimination of intermediate annealing are stressed (17 refs).—R.P.

A recent development of the LD process R. Rinesch (*Berg. Hütten. Monatsh.*, 1960, 105, Nov., 302-313). After giving a brief historical review of the LD process, the author discusses recent developments aimed at making the process more widely applicable. The effect of nozzle shape on the reaction zone is dealt with in detail.—R.P.

New LD steel converters made by Voest W. Hitzinger (*Auer Steel, Stahl*, 1961, 26, May, 213-218) [In French] After an account of the development of the LD process in Austria and its extension and adaptation abroad the part played by the plantmaking division of Voest in supplying converter plant for overseas customers is described.

Instrumentation for an LD process plant D. J. Pearce (*ISA Proc.*, 1960, 10, (10), 1-10).

LD steel progress: Over 30 million tons annually by 1963 (*Met. Bull.*, 1960, Sept. 27, i, iv). Twenty works in operation on Sept. 1 1960 are listed. The time they have been operating, no. and capacity of converters, and annual LD capacity (metric t), are tabulated. The same data is provided for 26 that are under construction or projected.—C.V.

The Stora Kaldø oxygen steelmaking process T. O. Dornsjø and D. R. Berg (*ISA Proc.*, 1960, 10, (1), pp.13). The metallurgy, operation, and economics are reviewed. A sketch of a 30-t Kaldø furnace is provided and a series of diagrams show the refining of high-, medium-, and low-P hot metal to low and high (and medium) C-steel; the O₂ content of Kaldø and electric steels is compared and the relative distribution of P, S, and N in Kaldø and Bessemer for low C-rimmed specification steels is shown together with the same for electric furnace steel for rimmed and semi-killed specifications. Finally the impact strength (Charpy V-notch) on lin (top of ingots) for normalized and normalized and aged (10% strained + 482°F/1 h) are shown for Kaldø and electric steel.—C.V.

The OLP hot metal refining process using pure oxygen and lime powder B. Trentini (*Techn. Mod.*, 1961, 53, May, 177-182) [In French] The Austrian LD process was developed to refine hematite iron low in P but cannot be applied to the high P (1.8%) produced in France. To refine this iron larger amounts of slag must be formed than with hematite iron and the oxygen jet must penetrate the slag to reach the metal below. In addition the elimination of phosphorus is not as easy as silicon and it is economically necessary that dephosphorization should be completed before the carbon is eliminated. The Kalling Kaldø process is described—Sollac has a 110-t furnace. In Germany the Rotor furnace has been developed. The Aceries de Pompey are operating a two slag process with additions of crushed lime and injecting lime powder into the oxygen jet. IRSID and at the same time ARBED with the LD/AC process found the solution to the problem.

Durgapur—A technical survey. Steelmaking plant (*Iron Coal Trades Rev.*, 1960, pp.218, 82-94). The overall design was undertaken by the Wellman Smith Owen Engineering Corporation Ltd, and the layout of the plant and salient sections is illustrated. Initially there will be seven 200-t and one 100-t OH furnaces; and annual production of 1 m. t is envisaged, but space is available for an ultimate 12 200-t furnaces. Details are given of ingot and wheel-ingot casting, of the limestone and dolomite burning plants, of the refractories used, instrumentation, ancillary equipment, and services.

Combined burner systems for open hearth furnaces H. Wirtz (*Demag Nachr.*, 1960, (159),

35-36). A description is given of the 'Dr. Schmitt' combined burner system, and its uses in OH melting and refining. Data are given to show the reduction in charging, melting, and boiling times using the burner system.

Heating OH furnaces with natural gas A. L. Turubiner (*Metallurg*, 1960, (8), 16) [In Russian] The following scheme has been introduced at 'Zaporozhstal' for heating with natural gas: approximately 40% of air is introduced into the gas regenerator, sufficient for the complete combustion of the natural gas. As the latter meets the air the hydrocarbons partly dissociate and precipitate carbon black which burns in the furnace giving sufficient luminosity to the flame.

The installation and operation of open-hearth furnace burners (*BISRA Rep.*, pp.32). A manual is presented embodying the results of research carried out by BISRA and individual steel companies designed to give guidance to steel-works engineers and operatives on the selection, installation, and operation of their burners. Working formulae and graphs simplify the task of the designer and an explanation is given of the importance of thrust and the necessity of avoiding unnecessary pressure drops in the atomizing steam or air supply lines.

Heating OH furnaces with cold gas of high calorific value without added fuel oil N. N. Dobrokhotov (*Metallurg*, 1960, (8), 13) [In Russian] To improve the luminosity of the flame the coke-oven gas must be self-carburizing. This can be achieved by introducing the gas in the furnace space in a thick stream under low pressure. The gas is then heated up to high temp. before it is mixed with air. The velocity of the regenerator air stream must be increased at the same time and the ports enlarged. Their surface should equal about one-twentieth that of the hearth.

Improvement in the operation of OH furnaces A. A. Sakharov (*Metallurg*, 1960, (8), 12-13) [In Russian] The improvements suggested by Stal'proekt are: thicker linings for the slag pockets; alterations in the air checkers (the five upper rows with Cowper, the ten lower ones with Siemens systems). Furthermore other changes are suggested for feeding oil fuel to the flame, for changing the compressed air pressure etc.

Improvement in the running of the OH furnace shop P. I. Novolodskii and B. N. Shisharin (*Metallurg*, 1960, (8), 12) [In Russian] At the NTMK the average steel production per m² of hearth surface was 10.6 t per 24 h and the production of the individual furnaces reached 308000 t/yearly which is a world record for furnaces of this capacity. The use of basic bricks for roofs increased the number of melts per roof from 188 to 479.

Rapid fettling of hearths D. F. Nagovitsyn (*Metallurg*, 1960, (8), 18-19) [In Russian] A time table is given for fettling a 50 m² hearth covering the first 10 days after the beginning of the operation.

Oxy-fuel processes increase steelmaking rates E. F. Kurzinski and R. D. Jones (*Iron Steel Eng.*, 1961, 38, Feb., 67-73). Operating practice in the use of oxy-fuel jets (oxygen + natural gas) in OH furnaces is described.

Aerodynamics of open-hearth furnace flames C. Holden (*'Major Developments in Liquid Fuel Firing, 1948-1959', Inst. Fuel*, 1959, A-37-43). For a given firing rate, the momentum or thrust of the fuel stream is the most important factor governing flame length. If the driving rate is increased, the fuel flow and momentum must also be increased; at these higher thrust values, recirculation of waste gases becomes appreciable so that for a fixed steam pressure a change in thrust produces only a small change in flame length. If the velocity of the flame over the bath is increased will raise the heat transferred by convection and the penetration of the flame into the scrap which can be achieved by increasing the inclination of the flame and putting it closer to the bath. The present trend is to design burners to give the maximum thrust for a given mass of atomizing agent but since the entraining power of liquid droplets is very low it is probably more profitable to design a burner in which the minimum energy is transferred from the atomizing agent to the fuel.—C.V.

Flow pattern as affecting open-hearth furnace designs A. Hogg and C. Holden (*'Major Developments in Liquid Fuel Firing, 1948-1959', Inst. Fuel*, 1959, A53-59). The flow patterns in open-hearth furnaces are discussed. The undesirable features such as bad inlet conditions at the base of the checkers, asymmetric flow in the uptake, and marked recirculation are instanced. It is shown that a rise of 50° in the preheat temp. improves inlet conditions and it is stated that the effect of recirculating gases between the flame and the roof is to reduce the heat transfer; therefore it has been suggested that a change in roof shape or uptake area will considerably reduce the amount of recirculating gases and thus improve the thermal efficiency. The provision of a readily adjustable burner would, it is considered, improve the performance of an OH furnace.

Liquid fuel for open-hearth furnaces: A ten-year review R. Mayoreas (*'Major Developments in Liquid Fuel Firing, 1948-1959', Inst. Fuel*, 1959, B-24-36). Apart from reviewing the progress in instrumentation, burners, etc., the problem of S in fuel oils will, it is thought, become aggravated. Apart from this low-S steels are being increasingly used and it is necessary to study more about the mechanics of S-pick up. The question of inhibiting or removing the S cheaply is also manifestly important.—C.V.

The cooling of open-hearth furnaces by vaporising water. (Steam cooling) Z. Vadas (*Koh. Lapok*, 1960, 93, Nov., 522-523). In Hungary, the cooling of door frames, skew-back channels, pillars, and uptakes of OH furnaces with vaporizing water produces steam and improves the economy of the steel melting plant.—P.K.

Combustion and heat transfer in the open-hearth furnace C. Holden (*Glass Techn.*, 1960, 1, Dec., 251-259). The heat available for steelmaking can be increased by increasing the fuel input, increasing the preheat temp., using O₂ for combustion, decreasing the amount of atomizing agent used or changing this, e.g. by using air instead of steam. The actual amount of heat transferred depends not only upon the heat available but on the bath coverage by the flame and this can be increased by increasing the angle of impingement or by increasing the number of flames used. The overall emissivity can be increased by carburizing, e.g. pitch with coke-oven gas or C with fuel oil. Recirculation of waste products over the flame should be eliminated (18 refs).—C.V.

Kinetic studies on steelmaking reactions. II. On the rate of carbon oxidation in liquid iron by oxygen blowing K. Niwa, M. Shimoji, T. Kishida, and Y. Itoh (*Tetsu-to-Hagane*, 1961, 47, Feb., 111-115). An expression is given whereby the total C removed from the liquid iron at high O₂ pressures can be calculated. The observed results agree closely with the theoretical.—C.V.

The physical chemistry of oxygen steel-making A. J. Kesterton (*Iron Coal Trades Rev.*, 1961, 182, Feb. 24, 397-400). A brief review and discussion. The general operating data are given, an analysis of a typical OH process slag being included for comparison while C, S, and P values after 1st and 2nd blow and ladle (S and P) are included and discussed. It is also shown that the ratio P:Mn in the steel sample after the 1st blow gives a clear indication of the slag basicity. Lower Mn levels indicate higher states of oxidation and the principal aim of the 2nd blow is to lower the P to <0.027% and it is shown that the length of this blow is based on the time required to raise the slag Fe to the desired level using the Mn after the 1st blow as a guide to the state of oxidation at the start of the 2nd. Superimposed on the indicated blowing times are the adjustments for fine lime addition to improve basicity, cooling, or ferro-silicon to raise the temp. In summary it is shown that the oxygen/steam process, both in theory and practice, is favourable to the production of steels of low-C and N content; this is the key to extra-deep-drawing quality steel.

Measurement of e.m.f. between slag and steel bath and its application to open-hearth process control K. L. Kiesel (*Neue Hütte*, 1961, 6, March, 157-166). The test procedure is described and relations between potential and

slag composition are discussed. Various theories on the origin of the potential are considered together with the possibility of applying potential measurements to charge control.

Automatic warning of break-through of metal at hearth fettling on banks of the steel furnaces A. M. Denisenko (*Stal*, 1961, (3), 231-232) A network of rods electrically connected is installed in sections under the hearth and banks of an OH furnace so that immediate indication is given if part of these is reached by the molten metal. The construction and wiring are shown and visual and audible signals are given.

The activity factor of manganese oxide in OH furnace slag and the diffusion of manganese during steel refining G. Violi (*Met. Ital.*, 1960, 52, Dec., 807-812) [In Italian] The ratio between the activity factors of the two oxides varies linearly with the content of acid components, in the slag. This ratio was established from OH steel and slag analyses. The factors determining and controlling the distribution of Mn between metal and slag during refining are examined with special reference to slag basicity and iron oxide activity.

The distribution of manganese between iron melts and iron (II) oxide slags in the MnO crucible at 1520 to 1770°C W. A. Fischer and H. J. Fleischer (*Arch. Eisenh.*, 1961, 32, Jan., 1-10) The melting point of Mn taking into account the O_2 partial pressure in the furnace atmosphere, was found to be $1875^\circ\text{C} \pm 25^\circ\text{C}$. As this result differed greatly from other reported values, the phase diagram $\text{FeO}-\text{MnO}$ was re-examined. The distribution coefficient of O_2 between slags with 98 $\text{FeO} + \text{MnO}$ and O_2 - and Mn-containing iron melts agreed with those of Taylor and Chipman for pure FeO slags, but the temp. relationship of the equilibrium constants of the reaction $(\text{FeO}) + [\text{Mn}] = (\text{MnO}) + \text{Fe}$ differed from those of previous workers. The deoxidation diagram of Mn was modified in accordance with the results obtained (36 refs.).

Oxy-fuel lance for O-H furnace Ford Motor Co. (*Iron Coal Trades Rev.*, 1961, 182, March 3, 463-464) A further report of this technique is given. The best results were being 70 t/h on a 200-t furnace with 1368 000 Btu/t and 1575 ft³ O_2 /t. Other results with a similar furnace and with a 400-t furnace are also given.—C.V.

Oxygen roof lancing in open hearth furnaces. I, II (*Indust. Heat.*, 1961, 28, Feb., 314-318; 345-352) Abstracts from the OH Conference. I. Operating data are given for practice at Gary Steel Works and the Ford Motor Co. II. Data are given for refractory performance from two works. Oxygen-lance practice is severe on refractories, particularly roofs, and indication are that a low-silica magnesite-chrome brick, chemically bonded, and internally plated, may give the best results.—K.E.J.

Results obtained with the use of automatic measuring and regulation equipment in open-hearth furnaces F. Rabes (*Neue Hütte*, 1961, 6, Feb., 65-71) [In German] Results of operation are given for partially automatic OH furnaces in the A plant and fully-automatic OH furnaces in the B plant. Status of measuring and regulation engineering uses in other steelworks of the German Democratic Republic are given. Results are compared with those previously published and existing equipment is criticized. Present and future demands made on manufacturers of measuring, regulation and control equipment are discussed.—R.S.F.C.

The swing to all-basic furnaces J. H. Chesters (*Glass Techn.*, 1960, 1, Dec., 243-250) It is only of recent years that all-basic furnaces have proved economical; at the beginning of 1960, 50 were in operation. The question of longer life is a specious argument; the economy lies in faster driving, greater input rate of fuel (with or without O_2), and increased outputs of 10-30% result with roof life two or three times that of silica despite the higher operation temp. (16 refs.).—C.V.

Temperature conditions for heats when steelmaking from phosphoric iron I. Yu. Kh. Kozhevnikov, A. G. Alimov, and K. A. Tikhomirova (*Stal*, 1961, (3), 228-230) In treating high-P irons large slag volumes are necessary and considerable temperature differences between slag and metal may arise.

Special Pt-Pt-Rh thermocouples were constructed for the measurements giving a cycle of 1.5-2 min for readings. The variations in slag and metal temp. during the heat are traced and the reactions and conditions are discussed.

Ball-bearing steels made from sponge iron as raw material M. Ueno, H. Nakajima, and S. Ikeda (*Tetsu-to-Hagane*, 1961, 47, Feb., 124-129) SKH ball-bearing steels, sponge iron, and scrap are used in the production of Japanese ball-bearing steels. It is the object of this investigation to determine the effect of the sponge iron. When >50% sponge iron was used, minor impurities such as Cu, Mo, and Sn were considerably decreased and as the charge ratio of sponge iron increased stringer- and oxide-type non-metallic inclusions rose but the Al_2O_3 -type did not change. The mean dia. of the spheroidized carbide lay between $0.84-1.04 \mu$ which is considerably higher than that found in SKF and New Departure ball-bearings. The behaviour of carbide solution differed only in one case where it did not go into solution at an austenitizing temp. of 840° on account of the presence of 0.2%V additive. Optimum results in a life test were found with 50% sponge iron+50% returned scrap and 100% sponge iron; in the second group were 50% scrap+30% returned scrap+20% iron sand and 0.2%V, 50% iron sand+50% sponge iron, 25% returned scrap+75% sponge iron while the least satisfactory contained 50% scrap+30% returned scrap+20% iron sand.

Production of stainless steels in the open-hearth furnace K. Protiva (*Hutn. Listy*, 1961, 16, (1), 7-12) [In Czech] Researches dealing with the most economical utilization of increasing quantities of austenitic scrap, frequently originating from Czecho-slovak stainless utility steels containing large amounts of Mn instead of Ni, are described. Details of the technology for converting such highly alloyed scrap to 18/9 Cr-Ni type steels are given. The use of 30-t OH furnaces was found most appropriate.—F.F.

Regenerator checkers of open-hearth furnaces J. Altneder (*Koh. Lapok*, 1960, 93, Oct., 445-451) The construction of regenerator checkers of OH furnaces heated with oil, or cold chamber gas and oil, or natural gas and oil is described; and the advantages of basic bricks, with the measures necessary for increase in the life of checkers, are discussed by the author. In fireclay checkers of 34 Seger cone, the permissible maximum temp. is 1350°C ; whereas, in basic refractory checkers, it is 1420°C .—P.K.

Possibilities of improvements to the aerodynamics of the OH furnace regenerators discovered by pattern studies A. Ramacciotti (*Met. Ital.*, 1960, 52, Dec., 772-778) [In Italian] By means of pattern studies a possible way of eliminating irregular flow of gas streams passing through the checker of an OH furnace during both air and waste gas phases was found. This is by constructing the furnace roof and hearth of a specially designed curved shape. Further research is being sponsored by ASSIDER.

A note on high temperature recuperation R. H. Phillips (*Glass Techn.*, 1961, 2, Feb., 35-38) The latest designs of metallic recuperators allow operation at temp. which approach the normal maximum which is obtainable with refractory recuperator. Despite the higher capital cost, they are worth while in view of the greater flexibility of installation and operation.—C.V.

Melting tests on direct reduced ferrous material in electric and OH furnaces O. Masi and P. Cannizzo (*Met. Ital.*, 1961, 53, Jan., 1-16) [In Italian] R-N briquettes were melted in 60-t electric and 50-t OH furnaces and the products compared with heats from normal charges using scrap. Favourable results are explained by the higher purity of the briquettes, and unfavourable results are thought to be due to the presence of residual iron oxides. Minimum total Fe content must be 90% for electric furnaces and 85% for metallic Fe. In OH furnaces slightly lower values can be tolerated.

Iron and steel in India. VI. The role of the electric furnace G. R. Bashforth (*Brit. Steel*, 1960, 26, 352-357) Types and capacities of

electric-arc furnaces in India are enumerated, with a discussion of the possibility of the use of the electric-arc furnace for tonnage steel production (21 refs.).

The development of electric arc furnaces G. Blackburn (*Close-up*, 1960, June, 10-11) A brief review.—C.V.

New trends in the design of electric smelting furnaces L. I. Moroz (*Stal*, 1961, (2), 130-134) A review of newer types including open and covered rotary furnaces, vacuum furnaces, fluidized beds, and hollow electrode types for charging.

Present trends in direct arc electric furnace applications. I. W. E. Lewis (*Indust. Heat.*, 1961, 28, Jan., 98-100) A survey is made of electric-arc furnaces used in making plain carbon steel ingots and steel and iron castings and applications to direct reduction processes, viz. the sponge iron, Strategic-Udy, H-iron, R-N, and Dwight-Lloyd-McWane processes.

Design principles for arc reduction furnaces K. L. Morikramer (*Elektrowärme*, 1961, 19, March, 110-116) Theoretical research on the arc reduction furnace has led to derivation of principles suitable for their design. Data for design is given on a series of parameters which include the electrode dia., the electrode pitch circle, and the transformer performance. The formulae were found sufficiently accurate for practical purposes by applying the results to installations in actual operation.—M.L.

Desulphurization and deoxidation of steels by injection (*Can. Mines, Research and Special Projects Report for 1960*, 1961, 10) Tests have been carried out with Ca-Mg alloy and lime, and lime-Mg mixtures which have been injected into steel in the basic electric furnace. Desulphurization is followed by analysis of the slag and metal. By using the double slag basic method, the charge being injected beneath a well-reduced basic slag, consistent X-reductions of ~50% occur; starting concn. were 0.03-0.01%. Silicate levels in the test were relatively high, thus preventing the desired basicity, but this factor is being further examined.—C.V.

Inductive stirring in arc furnaces (*Austr. Mech. Eng.*, 1961, 48, Jan. 5, 34-36; from a paper at the Stresa International Congress) Use of the stirrer results in greater homogeneity and gives more accurate temp. measurements; chemical reaction between steel and slag are speeded up and approach nearer to the theoretical equilibrium, S- and O-concn. being kept at low and uniform levels. It is also found that deslagging is simplified and impurities in the steel are reduced.—C.V.

Melting and refining: Uses of directly-reduced iron (*Can. Mines, Research and Special Projects Report for 1960*, 1961, 9-10) Several heats of ferritic cast steel LCB (ASTM A 352) were used; this is specified for low temp. service to meet a minimum 15 lb impact strength at -45° . This steel is made in an electric arc-furnace from direct iron produced by the Quebec Iron and Titanium Corporation, Sorel. This 'Sorel-metal' is supplied in pig form. With heats made from this, the specified minimum impact strength was from -60 to -75° depending on the heat-treatment given. Tensile properties also exceeded the minimum specifications. The improvement in these mechanical properties is attributed to the low concentration of S, P, and residual elements present.—C.V.

Electric steel ... Degassing and furnace maintenance E. Franzen (*Found. Trade J.*, 1961, 110, Feb. 16, 207-208) The practical application of modern techniques to two aspects of steel production for foundry purposes is discussed with special reference to the maintenance of the furnace bottom. The greatest cause of high bottoms is improper draining of the slag and the most inexcusable cause of the build-up is due to the furnaceman. A vertical contour between the bank and the lining should be maintained and high tapholes which prevent proper draining are a constant source of trouble. Means of removing taphole ridges either by mechanical means or by O_2 -lancing should always be available.—C.V.

Remelting CrNiMnN austenitic scrap K. Löbl and K. Hybek (*Hutn. Listy*, 1961, 16, (1), 13-19) [In Czech] Details are given of the development of technology for the utilization of scrap

obtained in the manufacture of Czechoslovak stainless utility steels containing large amounts of Mn to replace Ni. Arc furnaces of $\frac{1}{2}$ -1-t capacity utilizing up to 60% of scrap in the charge were used. The application of oxygen lancing in the process is described.—P.R.

The electroslag remelting of steel A. F. Tregubenko, V. G. Speranskii, and S. A. Leibenzon (*Stal'*, 1961, (3), 233-238) An electric furnace with six moulds (of water-cooled copper) using the process is described. It is considered that the process could be put into operation on a full commercial scale and the construction of special shops is advocated. The production of large ingots is advised.

Steel J. C. O. Harris (*US Bur. Mines, Bull.*, 1960, (585), 767-792) A general review.

Semi-killed steel J. Uříčák (*Hutn. Listy*, 1961, 16, Feb., 88-94) [In Czech].

Co-operative tests on ingot moulds André, Delayen, Poissonnier, Guérithault, Ledoux, Marcus, and Duflet (*Fonderie*, 1961, Jan., 22-25) Co-operative tests are tabulated which were carried out by two societies, each using 20 ingot moulds of their own and 20 supplied by the other organization. Layout, method, and casting conditions as well as analyses of melt used are given. Results are compared and analysed statistically.—R.P.

Investigations of improvement of raw ingot surface by use of corrugated pasteboard W. Krauskopf (*Radex Rundsch.*, 1961, April, 543-545) The ingot surface of bottom poured moulds is frequently spoiled by non-metallic spots, due to non-metallic inclusions embedded in the outer surface, close to the slag skin, which during the casting adhere to the mould walls. A study of this phenomenon has resulted in the conclusion that the slag skin must be kept away from the walls, and this was accomplished by jamming a honeycomb-like corrugated pasteboard near the bottom of the mould. The improvements to surface were significant both from the viewpoint of decreased weight loss and reduced costs for the conditioned ingots.—M.L.

Floating hot tops with ceramic rings B. I. Panich, V. I. Khmirov, and D. P. Ulyanov (*Stal'*, 1961, (3), 225-227) A design with ceramic rings on blocks at the bottom to float in the steel is described. This is fixed with waterglass under a thin refractory layer. The deficiencies of the present design are discussed and recommendations for further trials are made.

Prevention of cracking in the parts of the base plate heated by the ingot N. I. Pavlovtsseva (*Stal'*, 1961, (2), 189-192) Tests are described carried out to identify the factors leading to cracking of the base plates. Thermal stresses rather than phase change, oxidation, or grain growth are the cause of cracking and reduction of heated area and coating with inserts to divide the beams raises life to 100-120 heats as against 50-60 for the original design.

High-percentage ferro-aluminium used for deoxidizing killed steel I. N. Lad'yanov (*Stal'*, 1961, (3), 222-225) Advantages over Al and over low-percentage Fe-Al are claimed. The cases in which high-percentage or low-percentage alloy is to be preferred are considered, the advantages of each being given.

Increasing the consumption of silico-chrome in stainless steel production F. I. Shveb, D. G. Zhukov, and A. M. Khizhichenko (*Stal'*, 1961, (2), 128-129) Combined deoxidation and alloying with Cr can be obtained by the use of Si-Cr. Trials with stainless steel to promote the use of Si-Cr are described, and a method of use which does not introduce Si into the steel was found. Use of Ti scrap instead of Fe-Ti also increases Si-Cr consumption and reduces the Cr content of slag.

Pouring practice changes evaluated ultrasonically A. C. Mager (*Steel*, 1960, 147, Oct. 17, 134-136) A series of tests of complete heats of steel from OH furnaces, leading to raised tapping temp., abandonment of pouring boxes, and SiC ladle additions, and the use of higher refractory ladle well toppings, with their results, is described.—S.H.-S.

Pouring tube steel into closed and open ingot moulds G. Libertini (*Koh. Lapok*, 1960, 93, Sept., 395-399; Oct., 456-459) Comparing ingots poured into closed and open ingot moulds, the author found less segregations, but

more and smaller inclusions in the former, than in the latter. The ingots poured into closed moulds showed inferior surface, but resulted in about 25% more yield, than those poured into open moulds. Ingots poured into open moulds and treated with 0.18-0.24 kg Al per t of steel during pouring showed the advantages of the ingots poured into closed moulds without their drawbacks.—P.K.

The continuous casting of steel M. S. Boichenko, V. S. Rutes, and N. A. Nikolayev (no source; 1960, pp.25; from *US Tech. Trans.*, 1961, 5, Jan. 13, 20) [No abstract].

Study on continuous casting of steel. IV. The mechanism of formation of inner cracks of cast billets K. Ushijima (*Tetsu-to-Hagane*, 1961, 47, Feb., 116-124) The mechanism of crack formation is essentially the same as that found in normal ingot casting but in continuous casting the effect of spray cooling and pinch rolling must be considered, as the internal force set up may become greater than the strength of the billet, and the inner cracks will be terminated by the still remaining molten steel. A model is presented showing the solidification within a billet, and macro- and micro-structures are given.—C.V.

The capacities of water spray nozzles in continuous steel casting plants A. D. Akimenko and A. A. Skvortsov (*Stal'*, 1961, 121, 124) Equations for water and water-and-air mixtures passing through nozzles of ordinary type are given with tables of the results.

Continuous casting in the manufacture of wire F. Leitner and R. Rossegger (*Wire World Int.*, 1961, 3, Feb., 17-20) If properly cast, continuously cast ingots of C-steel and low-alloy to medium alloy steel are equivalent to ingot cast steel as far as quality and machineability for wire drawing are concerned. Hot-working costs up to the wire stage can be considerably reduced as the rough cogging operation is eliminated. This process is in the course of rapid development at the Breitenfeld Steel Works, Austria.—C.V.

Production of stainless steel billets in the Schoeller Bleckmann continuous casting plant B. Matuschka, M. Petz and F. William (*Met. Ital.*, 1960, 52, Dec., 765-771) [In Italian] A description of the development of continuous casting at the works of Schoeller Bleckmann in Austria with special reference to the production of stainless and heat-resistant steels. Full details of operations with production data are given.

Contribution to the study of solidification isotherms of steel ingots P. Ravizza (*Met. Ital.*, 1960, 52, Dec., 801-806) [In Italian] The crystalline structure and liquation zone of the ingot are connected with the isothermal solidification surfaces after casting. This study attempts to show how these surfaces develop under the action of the side and bottom cooling speeds. The effect of a water-cooled bottom plate has been examined which improved the crystalline structure by speeding up the solidification of the ingot base. Results and conclusions are set out.

Study of the influence of vibrations on steel ingot solidification P. Ravizza (*Met. Ital.*, 1960, 52, Dec., 795-800) [In Italian] Vibration tests were carried out on metal alloys during solidification after casting. Vibrations with frequencies of from 25 to 200 Hz and amplitudes from 0.7 to 4 mm were directly applied to the hot top and base of the ingot. In all cases substantial reductions in grain size and carbide mesh due to the vibrations were observed and proposals for the practical application of this technique are made.

Effect of low-frequency vibrations in the mould on ingot crystallization V. I. Leontyev (*Problems of Metallography and the Physics of Metals*, 1959, 28-31; translation from Russian). Initial experimentation was carried out with a transparent mould using transparent liquids and Hg and the effects of frequency and amplitude were studied in this and with normal moulds. The motion of the molten mass was shown to differ quite markedly at low frequencies (~20-50 cps) and at higher values (~200-500 cps) and photomicrographs of the resultant structures of steel and Zn (with and without 1%Sn) are shown for varying f and v values.—C.V.

The thickness of skin and distribution of sulphur in rimming steel ingots G. Odone and A. Filippini (*Met. Ital.*, 1960, 52, Dec., 786-794) [In Italian] Among the factors affecting the quality of rimming steel are the segregation of the sulphur and the distance of the primary blow holes from the surface of the ingots, which is called skin thickness. In order to find out more about the variables which control these factors an examination was carried out to explain the relation between skin thickness and type of rimming steel and the dependence of the distribution pattern of sulphur in ingots from the rimming process and the size of the ingots.

FOUNDRY PRACTICE

An example of modernization and rationalization: the metamorphosis of the Bondy Foundries G. Sorin (*Mécan. Electr.*, 1959, 43, Oct., 50-58).

Small-scale mechanization in foundry practice H. Hohlfeld (*Giessereitechn.*, 1960, 6, Aug., 225-229) A description of measures taken to mechanize the finishing processes and transport techniques in a medium-sized foundry.

Pneumatic conveyance of coal dust, bentonite and quartz sand W. Döbber (*Giesserei*, 1961, 48, May 18, 293-295) The design and operation of a pneumatic conveyance installation for coal dust, bentonite, and quartz sand, are described. The installation comprises facilities for emptying bins and sacks, storing bins, and conveyors for operational bins and the processing installation. The analysis of cost indicate the economical advantage of the pneumatic conveyance over manual transport.—M.L.

Several possibilities of compounding cupola furnace charges R. Bluhm (*Giessereitechnik*, 1961, 7, April, 99-105) A survey of facilities and installations for compounding charges for cupola furnace; designs and applications are discussed.—M.L.

Refractory linings for cupolas I. Lamoureux (*Fond. Belge*, 1961, 31, March, 77-78).

Special measures in the cupola melting process—Part 2 W. Friedel (*Giessereitechnik*, 1960, 6, Aug., 241-243) The duplex process cupola-electric furnace is discussed. **Part 4** (Dec., 363) The effect of oxygen additions on cupola melting practice is discussed, using intermittent and continuous additions. It is concluded that special measures such as pre-heating stoves for hot blast, oxygen plant, and electric furnaces are justified.—R.P.

A recuperator for heating the cupola blast R. Chudzikiewicz and T. Kukala (*Prz. Odlew.*, 1960, 10, (12), 340-345) The recuperator made of 5 mm steel plate sprayed with Al (1 kg/m²) has been installed in the stack of the cupola. The temp. rose to 450°C as did that of the iron from 1320° to 1460°C at a coke rate of 12%. The CO content in the waste gas increased but the sulphur content dropped, less Si was slagged off, and the C content increased. The fluidity of the metal remained good despite the inferior quality of the coke used. The lining, however, suffered so badly that water cooling had to be applied if the cupola was to be run for more than 8 h.

Production costs using the Duplex electric fore-hearth cupola process C. Fessina (*Fonderia*, 1961, 10, (5), 199-205) [In Italian].

Electric furnaces in iron foundries R. Genwo (*Demag Nachr.*, 1960, (159), 28-34).

Induction heating in the metal industries: heating and melting (*Edgar Allen News*, 1961, 40, April, 78-79).

Electric arc and induction melting furnaces K. Schulz (*Electrowärme*, 1961, 19, April, 153-158) A review of the various designs.—M.L.

Vacuum induction melting-oxygen and carbon in iron J. E. Srawley (*NRL Rept.* 5516, 1960, Sept., pp.17) Oxygen contents of 200-300 ppm were reduced to ~20 by C addition. Reactivity of crucible materials was noted.

Birdsboro converts foundry to electric steel production (*Iron Steel Eng.*, 1961, 38, Feb., 145).

Grey and white cooling of cast iron M. Hillert (*Gjuteriet*, 1961, 51, (4), 53-58) Cooling of cast iron sometimes starts with grey structure followed by white. The process has been followed in detail with the following conclusions. Initial grey cooling is due to graphite

readily forming a core; Si favouring this is due to the core formation. Rapid cooling favours white hardening and is due to core formation of cementite being more favoured by cooling than that of graphite. Grey rim and core white: the change occurs when favourable conditions have arisen in any part of the ball. These favourable conditions may depend on local reduction of temp. or segregation of certain elements. After core formation the cementite spreads rapidly and dominates hardening of the rest of the ball.

Guide to construction of cast goods. I A. Östberg (*Gjuteriet*, 1961, 51, (2), 15-25).

The causes and prevention of rejects in chill-cast grey iron. Part 2 K. Herfurth (*Giessereitechnik*, 1960, 6, Dec., 364-367).

The theory of spheroidal graphite crystallization W. Patterson and D. Ammann (*Giessereitechnik*, Wiss. Beihefte, 1961, 13, 65-70) After reviewing the known theories concerning spheroidal graphite formation an hypothesis is advanced which is an amplification of the boundary surface energy hypothesis of B. Marinček. Lattice energy considerations and explanation of the laminar form of graphite usually found in cast iron are the basis for this hypothesis, which states that the boundary surface energy of graphite towards iron is strongly anisotropic. Theoretical computations based on the hypothesis are in good agreement with experimental data (29 refs).—M.L.

Importance of process control in producing dross-free nodular iron castings R. Barton and A. G. Fuller (*BCIRA J.*, 1961, 9, May, 406-418) The following recommendations are made based on the experimental work discussed: (1) Strongly hypereutectic irons should be avoided, (2) irons with lowest S-content should be used, (3) soda ash is preferable to CaC_2 for decarburization, (4) analysis for C and S should be carried out where possible before Mg treatment, (5) Al content should be $<0.01\%$, (6) accurate control of weights and temperature to be enforced, (7) residual Mg-content to be minimum consistent with formation of satisfactory graphite structure, (8) treatment to be suitable to the melting equipment available and should yield high metal temp. after treatment, (9) narrow and deep ladles should be used rather than wide and shallow ones, (10) a ladle cover should be provided, (11) casting time to be as short as possible and ladles should be preheated, (12), the use of Te to reduce dross defects is not a substitute for adequate control, (13) green sand moulds should be used, dry sand moulds should be blacked and oil-bonded core sand moulds are most likely to cause dross defects, (14) for a similar residual Mg content, neither chemical composition of the alloy nor Mg recovery affect the incidence of dross defects, and (15) the gating system should be designed to prevent splashing and turbulence.—C.V.

Notes on the inoculation of irons (*Fonderia*, 1960, 10, (5), 221-222) [In Italian].

Basic cupola melting of ductile iron J. T. Williams (*Trans. AFS*, 1959, 67, 669-670) With reasonably uniform ingoing returns, clean scrap and a well-lined cupola, fairly consistent results may be ensured but erosion of a large portion of the lining can drastically change the basicity of the slag. Among the advantages of basic cupola melting one finds, low S-iron can be tapped from the cupola, high C-pick-up allows the use of lower cost, low-P steel scrap, a somewhat higher tapping temp. and good slag fluidity. On the other hand, higher daily patching cost, lining costs, higher Si-loss during melting, greater volume of slag to handle, higher fluxing cost, and the greater skill and more exact control required can be disadvantageous.—C.V.

Special measures in the cupola furnace melting process K. Haensch (*Giessereitechnik*, 1961, 7, March, 80-82) The effects of low-melting-point carbide additions to the smelting coke in the cupola furnace melting process were studied; it was found that these increase the temp. and fluidity of the Fe, thereby increasing the furnace productivity and improving the cast iron quality at the same time. Significant savings of high value smelting coke were also obtained, and more than compensate for the losses due to increased erosion of the

furnace lining. Another effect observed, of marked significance in the case of Bessemer steel castings, is the reduction of the S content—from 0.130 to 0.095%.—M.K.

The carburization of iron in cupola furnaces R. Krzeszewski (*Acad. Romine, Studii Cerc. Met.*, 1960, 5, (4), 443-469) The relationship between the content of C in the cast iron of cupola furnaces, the contents of C in the charge, the chemical composition of the Fe, its temp., the working conditions in the cupola and the quality of the coke is expressed by means of two formulae which were derived on the basis of the kinetics of C dissolution in liquid Fe and of the oxidation in an oxidizing atmosphere. Good agreement was found between these formulae and the experimental data (63 refs).—M.L.

Graphite injection through tuyeres of a cold blast cupola H. J. Leyshon, R. B. Coates, and K. E. L. Nicholas (*BCIRA J.*, 1961, 9, March, 189-198) To obtain a high-C metal content from an acid-lined cold blast cupola, a high percentage of pig iron or a high coke charge/metal ratio must be employed. Alternatively carburizing agents can be added to the ladle or receiver. Both these methods suffer from practical and economic disadvantages. The present suggested method injects powdered graphite using compressed air as a carrier gas through one of the tuyeres of the cupola. The details are given and the effects on casting properties, specially chill and shrinkage, are discussed. The introduction of graphite results in a substantial C pick-up. The possibility of a reduction in cost of cupola charge materials is considered and it was noted that the metal produced showed a reduction in chill and shrinkage.—C.V.

Foundry applications of the IRSID T.W.A. process for the desulphurization of liquid pig iron by injecting powdered lime B. Trentini, J. Raguin, and J. Dufiot (*Publications d'IRSID*, 1959, Series A, (203), Sept., pp.15) The results of a number of foundry trials of this process are described; the method itself, which involves the injection of powdered lime in a stream of air or other gas through tuyeres in the bottom of a specially designed ladle, is not described in detail. The high degree of desulphurization attained suggests the value of the process for producing ductile iron.

Desulphurizing iron by injecting calcium carbide R. B. Coates (*Fonderia*, 1961, 10, Jan., 5-11) [In Italian] Special methods of desulphurizing cast iron are becoming increasingly essential. This article, taken from work carried out by the BCIRA in collaboration with British Oxygen Research and Development Ltd, describes experiments carried out to ascertain the advantages of injection of CaC_2 . The costs of using this method are also analysed.

The use of calcium carbide in melting grey cast-iron in acid cupolas D. Stráský, M. Kačír, and O. Matoušek (*Slévárenství*, 1961, 9, (1), 8-10) [In Czech] Carbide additions result in an increase of the temp. of the iron, and are suitable where high melt temp. are desirable, e.g. on inoculating or when high casting temp. are required. Cupola performance may increase by 10-15%, and from the metallurgical point of view carbide additions are also advantageous. The process could be used more widely if foundry carbide cost less.—P.F.

An improved method of desulphurizing cast iron with sodium carbonate R. B. Coates and R. Williams (*BCIRA J.*, 1961, 9, March, 263-278) The molten metal is tapped on to a bed of Na_2CO_3 and agitation is provided by compressed air introduced through a submerged lance. Using basic-lined vessels and a metal temp. before mixing of 1400°C , a 1% addition of Na_2CO_3 will reduce an S content of 0.15% to $<0.01\%$. The equipment is illustrated and the results for acid and basic-lined ladles are tabulated.—C.V.

New process for foundry iron T. E. Ban, B. W. Worthington, and C. D. Thompson (*Mod. Castings*, 1961, 39, March, 95-102). A description of the D-LM process for making iron is presented. The process makes use of low-grade raw materials, conventional metallurgical equipment and techniques of pelletizing, carbonizing, and smelting.

Electric melting in the foundry E. Zingg (*IGK Kongress-Vorträge*, 27th International Foundry Congress; Zürich, 1960, 277-294) [In German].

Indirect arc electric furnace production of ductile iron L. Miller (*Trans. AFS*, 1959, 67, 653-660) The indirect arc rocking furnace is of small capacity and rather slow for the melting of ferrous metals. Because of its design it does not lend itself to refining or slagging operations; it also lacks the electrodynamic stirring action of the induction and direct arc furnace. Consequently higher initial temp. have to be attained to break down or dissolve graphitic carbon in the base iron prior to the Mg treatment. Special refractory shapes are required to line the furnace and only high grade refractories can withstand the high temp. employed. The advantages lie in simplicity, the ability to handle a large variety of ferrous and non-ferrous metals giving a consistent performance; quality depends entirely on the degree of control. The use of the Mg alloy plunger ladle is discussed.—C.V.

Behaviour under operational conditions of high, medium and low frequency crucible furnaces in melting steel and heavy non-ferrous metals E. Gvelessiani (*Fonderia*, 1961, 10, March, 95-104) [In Italian].

An economic and technical study of the contribution of low frequency induction furnaces to the modernization of foundries G. A. Tagliaferri (*Inst. Hierro Acero*, 1960, 8, Oct.-Dec., 871-881) [In Spanish].

Water recooling equipment for electric melting furnaces W. Fritsche (*Giesserei*, 1961, 48, April 6, 166-170) Water recooling equipment in electric melting furnaces, especially arc furnaces, was surveyed with respect to the various types and their characteristics. It was shown that the considerations apply to similar equipment in induction crucible furnaces, pressure casting, chill mould casting, and extruding casting installations. Automatic control and safety devices are described in detail.—M.L.

Electro-slag remelting of steels and alloys in water-cooled copper moulds B. E. Paton, B. I. Medovar, and Y. V. Latash (*Iron Steel*, 1961, 34, March, 102-104; from *Automat. Svarka*, 1958, (11), 5-15) Compared with ingots cast by arc process, electro-slag cast ingots have a completely smooth surface; they require little or no roughing before hot mechanical treatment. ac is used for this remelting while arc remelting requires dc. In electroslag remelting, ingots of the most diverse cross-section can be cast and the ratio of ingot to electrode dia. can be 3:5 while with arc remelting this ratio must not exceed 1:5; if greater, the ingot surface quality deteriorates. In this form of remelting, the slag is able to react with the metal and this enables ingot metal S content to be reduced by a factor of 6 and remelting is considerably simpler and more reliable than with vacuum or gas shielded equipment. Other aspects are also discussed (23 refs).—C.V.

The use of spheroidal cast-iron at elevated temperatures A. Plešinger (*Slévárenství*, 1961, 9, (3), 93-101) [In Czech] On the basis of extensive metallurgical studies and creep tests it is shown that ferritic cast-irons of type 00 are suitable for the production of turbine armatures working up to at least 400°C .—P.F.

On Ebara OZ ductile cast iron E. Kawamura (*Ebara Times*, 1959, 8, Dec., 200-207; from *Japan Sci. Rev. Mech. Elect. Engr.*, 1960, 7 Aug., 271) [No abstract].—C.F.C.

The behaviour of silchrome steels in cast items C. Butnaru and T. Balatescu (*Met. Constr. Masini*, 1961, 13, (1), 10-13) The performance of silchrome steels containing 0.4-0.5% C, 2.5-3.5% Si, max. 0.70% Mn, max. 0.035% P, max. 0.035% S, 8-10% Cr was studied, determining the effects of variations in composition and in heat-treatment on the mechanical and structural characteristics. It was found advisable to subject cast items made of these steels to a thermal treatment comprising normalization at $950-980^\circ\text{C}$ (the Ac_3 point is $\sim 960^\circ\text{C}$) and recovery at 750°C followed by strong cooling in air.—M.L.

Development of low alloy steel compositions suitable for high strength steel castings H. R.

Larson, R. C. Campbell, and H. W. Lloyd (*PB* 171065, 1960, July, pp.75; *WADC Tech. Rep.* 59-63 Part II; from *US Res. Rep.*, 1961, 35, Jan. 13, 91) Heat-treatment and fatigue properties were studied, as well as high temperature behaviour.

Sand circulation in the foundry A. Dünner (*Giesserei*, 1960, Dec. 29, 47, 753-762).

Moulding and additives W. P. Winter (*Foundry*, 1961, 89, Apr., 102-107) The use of a variety of additives, including wood flour, sea coal, graphite, pitch, fuel oil, cereal flours and dextrin, also chemical additives and sodium salts, and their effects, are described and explained.—S.H.-S.

New technique of gating L. E. Carr (*Foundry*, 1961, 89, Apr., 81-83) The casting of 2½ in test cubes of stainless steel off a hollow sprue of ¾ in mean wall thickness and the resulting test work are described.—S.H.-S.

An evaluation of feeding heads and feeding aids for castings Institution of British Foundrymen (*Brit. Found.*, 1961, 54, Feb., 66-90).

Progress in the development of the 'Buhner' moulding and casting plant W. Götz (*Giesserei*, 1961, 48, April 20, 194-202).

Chemically treated saccharide binders I. Macásek and V. Lorenz (*Slévárenství*, 1961, 9, (2), 41-46) [In Czech] Experiments designed to improve core mixtures in which saccharide binders are used showed that in the case of 'Dextroner', ammonium sulphate additions increased the dry strength of the cores, also reducing moisture uptake very considerably.

Effects of mould dressings on casting fluidity of some alloys B. P. Betts and V. Kondic (*Brit. Found.*, 1961, 54, Jan., 1-4) The effect of mould dressings applied with different types of bond on the fluidity of 0.4% C steel, and cast iron and non-ferrous alloys, was determined using a thin strip-type mould made by the CO₂ process. Oxide based dressings, especially talc, gave the best results and the fluidity increased with a decreasing grain size of the dressing.

Carbon pick-up by stainless steel castings made in resin-bonded sands B. K. Kaplish and H. T. Protheroe (*Brit. Found.*, 1961, 54, Jan., 26-33) The conditions and extent of carbon pick-up by the surface of mild and 18-8 stainless steels cast in shell moulds and resin bonded sands was investigated. The source of the carbon is the carbonization of the resin and the effect of resin content, casting thickness, and casting temperature were established. A carbide-free zone of austenite is formed on the surface of stainless steels.—A.D.H.

Large steel castings for heavy duty H. W. Balster (*Met. Prog.*, 1961, 79, Jan., 89-93) Basic electric furnaces with a capacity > 25 t and with induction stirring are used for alloy steels. A Cr-Mo-V analysis, similar to type 316, has been widely used for high temp. work while the 13%Cr-steel is applicable for corrosion resistance. Welding of simple shapes into complex assemblies is common practice and examples are given.—C.V.

Centrifugal casting J. B. McIntyre (*Found. Trade J.*, 1961, 110, Apr. 13, 459-470) A detailed review of recent progress.

On the effect of the dropwise separation of metal from surfaces during centrifugal casting on the quality of the product N. N. Reutov (*Stal*, 1961, (4), 372-374) In contradiction to the reports of Tsvetnenko and Rulla (*idem*, 1959, (11)) multigonal structures in centrifugal castings are not caused by separation of drops by too slow rotation of the mould but to secondary sputtering caused by the break away of the skin under the influence of shock or vibration.

Comments on N. N. Reutov's paper K. U. Tsvetnenko and N. V. Rulla (*Stal*, 1961, (4), 374) See previous abstract. With further explanations of terminology the original conclusions are supported.

Automated shell mould line for port valves R. H. Herrmann (*Foundry*, 1961, 89, Apr., 58-61).

Large, intricate parts of all metal types precision cast by ceramic mould technique British Industries Corp (*Indust. Heat.*, 1960, 27, Nov., 2450-2451, 2458) The Shaw process may be used for all metals, including stainless, tool and die steels and high-temp. alloys. The mould

is made from blended refractory powders and a binder based on Et silicate. It is readily stripped, and when fired develops a 'micro-crazed' structure; this is not susceptible to thermal shock and allows gases to vent through it.—K.E.J.

Pouring ladle forms at Texas Foundries S. O. Smith (*AIMME, Proc. Elec. Furn. Conf.*, 1959, 17, 405-406) Small pouring ladles at Texas Foundries Inc. are hand-rammed round a metal former. A description is given of the former, which is specially designed for lightness and ease of removal.—E.F.

Teapot ladle design and split ramming cone J. M. Calkins (*AIMME, Proc. Elec. Furn. Conf.*, 1959, 17, 407-409) Brief details are given of the 'teapot' ladle design of Unitcast Corp., and a ramming former which is split for ease of removal is described.—C.F.

The treatment of cast iron melts by ultrasonics A. Kolorz (*Giesserei*, 1960, 47, Aug. 25, 447-451) The technique used is described and results discussed. Comparative trials on treated and untreated melts showed no differences in tensile strength, Brinell hardness and bend strength.

Instrumentation in alloy foundry controls and speeds charging and pouring operations General Steel Castings Co. (*Indust. Heat.*, 1960, 27, Oct., 2100-2104).

The shrinkage of grey cast iron J. Bradík (*Slévárenství*, 1961, 9, (3), 86-93) [In Czech] The measurement and control of the graphitization contraction is discussed in the light of the literature and of experiments carried out by the author. The use of a shrinkage test utilising a star-shaped test casting having a tapered central bore is described.—P.F.

Stresses in castings due to the alpha-gamma transformation J. Příbyl (*Sborník*, (Ostrava), 1960, 6, (3-4), 315-325) [In Czech] The control of cooling rates and of design features to minimize distortions and internal stresses in castings due to the volume changes arising from the $\alpha \rightarrow \gamma$ transformation are discussed.

Machine for treating iron with magnesium (*Fonderia*, 1961, 10, (4), 144) [In Italian].

Experiments on the use of cerium to compensate for interfering elements in the production of nodular graphite cast iron H. Grossmann (*Giessereitechnik*, 1960, 6, Dec., 370-374) Interference by residual elements on the formation of nodular graphite is discussed with special reference to Ti. With low Ti contents, additions of Ce increased the tendency towards solidification of a metastable phase and result in unfavourable mechanical properties of annealed ferrite. Hardness in the as-cast condition did not increase with high Ti content. Tensile strength and elongation of annealed ferrite increase up to 0.01%Ce.—R.P.

Testing of cast iron with nodular graphite G. Sille, W. Lewerenz, and R. Wahren (*Giessereitechnik*, 1960, 6, Dec., 358-362).

Structure of malleable cast irons with various Mn/S ratios. The influence of silicon C. Hisatsune and S. Mori (*Imono*, 1960, 32, Aug., 561-570) Graphitization of malleable cast iron (2.4%C, 1.0-3.0%Si, 0.4%Mn, and 0.02-0.1%S) was examined. S markedly inhibits early graphitization but Si has an accelerating influence. With increasing Si content, graphite is present in lump or star form; with low Si and high S it is spheroidal. When free FeS is present, the spheroidal graphite precipitates out.—C.V.

Ductile iron in steel mills C. R. Isleib (*Iron Steel Eng.*, 1961, 38, Feb., 83-91).

A Belgian steel foundry in India H. Godfroid [*Dalmia Iron and Steel Ltd*] (*Fonderie Belge*, 1961, 31, April, 91-95) [In French].

Application of chilling and heat insulating materials in steelfoundry F. D. Obolenzew (*Found. Trade J.*, 1960, 109, 261-269) In some present-day practice, the ratio of sound castings to metal used may be small and heavy expenditure may be required in cutting-off heads and for special additions such as webs and pads. Chilling media, metals (Cu-alloys, cast-Fe), high thermally-conductive materials (SiC, magnesite, chromite, etc.), sand moulds (green and dry), etc., are examined and slush-casting is carried out in hexagonal or square moulds so that four or six moulding materials

can be tested under identical conditions in one test, and numerical values are assigned to the chilling effect. It is shown that controlled solidification is possible using the above materials as well as chamottes. Heat insulating and exothermic materials are discussed and the problems connected with large or Maltese cross-shaped castings are considered.—C.V.

Steel foundry automatic sand mixing H. L. Kurtz (*Iron Age*, 1961, 187, May 4, 88-89).

Considerations regarding olivine sand and some other moulding materials for casting steel A. Hultdt and K. Beckius (*Jernkont. Tek. Rad.*, 1959, 20, (254), 337-403) Olivine, zircon, chamotte, magnesite, the kyanite group, and graphite are each dealt with separately and compared with quartz sand. Olivine is then dealt with in detail: geology, mineralogy, effect of crushing, heating and cooling, hygienic considerations in its use with reports on investigations into the reaction of lung tissues. Reports on use in foundries. Conclusions are that olivine sand does not cause silicosis, and the question of successful use in steel foundries has not yet been solved.

Olivine moulding sand against silicosis in steel foundries (*Tek. Tidsk.*, 1961, 91, (16), 412-414) The causes of silicosis and preventive measures of a practical and medical nature are stated, including particularly the use of olivine sand for moulding. The technical utilizability and biological effect of this are explained and successful use in Norway recounted. Some Swedish foundries have adopted olivine sand for moulding with virtual elimination of dust.

Synthetic sand in the heavy metal foundry F. Reile (*Giessereitechn.*, 1960, 6, Aug., 243-244).

How to improve the quality of moulding sands Z. Wertz (*Prz. Odlew.*, 1961, 11, (4), 105-112) Various mixtures have been exposed to the action of heat (1100°C for 1 min) and the macroscopic changes thus produced have been observed. The best mixture was that of 100 parts of quartz sand (sintering point > 1350°C), 15 parts of clay, 8 parts of coal dust (31.2% of volatile matter, 3.2% of ash), and 2 parts of peat, the moisture content of the mixture being 5.5%.

Use of a movable cantilever sand slinger unit for improving the operations in a hand moulding shop H. A. Krall (*Giesserei*, 1961, 48, May 18, 269-283).

Control of foundry sand G. Barchiesi (*Fonderia*, 1961, 10, (4), 139-143) [In Italian].

Relation between permeability and void of foundry sand K. Hashimoto and I. Takahashi (*Rep. Gov. Ind. Res. Inst., Nagoya*, 1960, 9, July, 324-328) The application of the equations hitherto presented concerning the relation between the permeability K and the void ϵ of foundry sand was studied. It was concluded that this relation can be expressed sufficiently well by the following equations in the range of the void in the usual mould, $K = \alpha \epsilon^3 / (100 - \epsilon)^2 + \beta$. Where α and β are constants, and α increases and β decreases linearly with the mean particle size of sand, d (mm), as shown in the following equations: $\alpha = 117d - 9$; $\beta = 50 - 462d$.—C.R.C.

Methods for the determination of humidity of moulding sand (1) H. J. Dietze (*Giessereitechnik*, 1961, 7, April, 109-112) The advantage of electrical measuring methods over non-electrical for the determination of moulding sand humidity is demonstrated by surveying the methods for humidity determination by means of measurement of the electrical conductivity, the dielectric constant, and the loss in the phase angle. These methods make possible full automatization of sand preparation installations.—M.L.

The influence of the temperature of preparation of synthetic moulding sands on their technological properties J. Szreniawski (*Prz. Odlew.*, 1961, 11, (2), 37-41).

Determination of the specific surface and angularity coefficients of sand grains L. Lewandowski (*Prz. Odlew.*, 1961, 11, (2), 41-44).

A study of the bonding forces between bentonite and silica sand S. Felio, J. M. Navarro, and H. F. Taylor (*Brit. Found.*, 1960, 53, June, 273-277) Tests are described which were undertaken to determine whether bonding

strength of sand-bentonite-water moulds was due to adhesive forces between clay and refractory or depended upon cohesive forces of the clay bond. Results indicated that on fracture the bond is broken through the clay face, and not through the silica-clay interface. Methods to improve bonding characteristics of bentonite-bonded moulding, sands must, therefore, be achieved by denser packing of sand or by improving the intrinsic properties of bentonites (chemical alteration), or by both means.—S.H.-S.

Effects of soluble chemicals on pH and properties of clay-bonded moulding sands W. R. Roberts (*BCIRA J.*, 1961, 9, May, 327-346) The pH of an aqueous sand-extract bears little relation to the actual pH of the sand; if Na_2CO_3 is added to sands, their properties change and the change is not directly related to pH and it is concluded that a base-exchange mechanism in the bonding clay has taken place. The bonding properties of Wyoming bentonite are partially destroyed by heating for 90 min at 400°, being almost completely lost at 600°; this decrease is accompanied by an increase in the acidity of the sand bonded with the clay and although treatment of the sand with Na_2CO_3 offset the increase in acidity, there was no appreciable alteration in the bonding properties of the clay.—C.V.

Cyclic permanent mould operation: Some thermal aspects C. L. Goodwin and H. Y. Hunsicker (*Trans. AFS*, 1959, 67, 431-435).

The carbon dioxide process G. D. Haley and J. L. Leach (*Mod. Castings*, 1961, 39, March, 121-124; *Fond. Ital.*, 1961, 10, (1), 21-24) The interrelated effect of the major variables in the process was investigated. Gassing time, gassing pressure, grain size of the sand, and amount of binder must be considered. A proposal for a standard testing method for CO_2 hardened sands is made.

Casting submarine parts in CO_2 process moulds R. H. Herrmann (*Foundry*, 1960, 88, Nov., 100-102).

Operational experiences with the CO_2 process results of an enquiry V. Kleinheyer and W. Schumacher (*Giesserei*, 1961, 48, Feb. 23, 92-96).

The use of waterglass-bentonite-sand mixtures without gassing with CO_2 M. B. Pajević and J. Krušpel (*IGK Kongress Vorträge*, 27th International Foundry Congress, Zürich, 1960, 251-261) [In German] Results are given of tests with mixtures of quartz sand and waterglass, with and without further additions and with and without CO_2 treatment. It is shown that satisfactory mould and core mixtures can be made on the basis of quartz sand and waterglass as a binder, with the addition of bentonite and molasses and mazut, without CO_2 treatment.

Cracks in mould make better castings Shaw Process Development Corp. (*Steel*, 1961, 148, March 6, 68-69) A process is presented, using deliberately induced microcracks in a ceramic mould, which is claimed to have various advantages in a wide variety of applications. Brief data are appended.—S.H.-S.

Urea-formaldehyde resin 121 as core binder J. Vereskői (*Koh. Lapok-Öntöde*, 1960, 11, Nov., 256-260).

Cylinder blocks beefed up with cast iron inserts Doehler-Jarvis Division, National Lead Co. (*Steel*, 1960, 147, Oct. 17, 128).

Cast iron fountain in the courtyard of the Archbishop's Palace in Cologne (*Giesserei*, 1961, 48, Feb. 23, 96-98) A description of the design and casting of the fountain, which is in the form of a decorated bowl 3 m in dia.

Casting a shaft for the 'Big Ear' (*Mod. Castings*, 1961, 39, March, 40-41) The manufacture of a 15 ft high, 10 ft dia. pintle shaft for the world's largest radio-telescope is described.

Design and application of investment castings produced by centrifugal methods I. L. Gwynn (*Proc. Eng. Materials and Design Conference*, Feb. 1960, London; 1960, D, pp.12).

Shell moulding. I A. Azzolini (*Fond. Ital.*, 1961, 10, (1), 11-20) [In Italian] Experience gained in Italy in the development of the process is described in detail.

Considerations in the use of plastic moulds in

foundries. II D. Iturrioz (*Met. Elect.*, 1961, 25, March, 77-85).

Shell-moulding of motor-cycle cylinders L. Kelemen (*Found. Trade J.*, 1961, 110, March 2, 275-277) It is pointed out that the selection of optimum casting position and runner system is specially important in shell-moulding, this being the more important since modification of expensive cast iron patterns is costly. It is necessary to take special precautions as regards ventilation since greater quantities of gas are evolved in a shorter time than with conventional methods. Examples of castings are shown.—C.V.

Casting iron into permanent moulds in East Germany F. Naumann (*Koh. Lapok-Öntöde*, 1960, 11, Sept., 191-198).

Shell moulding developments in the automotive industry H. C. Grant (*Trans. AFS*, 1959, 67, 641-652) Some 64 illustrations of different aspects of the shell moulding processes are provided. Crankshaft production is specially chosen for indicating the advantages.

The solidification equation of sand castings W. Koppe (*Giesserei Techn. Wiss. Beih.*, 1960, (28), April, 1535-1543) An equation is first derived by idealizing the conditions, and examining the flow of heat across the casting-mould interface. A corrected equation is then developed, and finally an equation is derived which is applicable to other mould materials (16 refs).

Grain refinement of cast metals G. W. Form, G. K. Turnbull, G. Gould, H. Merchant, and J. F. Wallace (*IGK Kongress Vorträge*, 27th International Foundry Congress, Zürich, 1960, 167-187) [In English] General principles of metal solidification in relation to grain size control are summarized, and it is shown how a fine equiaxed as-cast structure may be achieved, and what methods of control must be adopted to refine the grain obtained on solidification. Results of recent work on the effects of vibration, inoculants, and additions on grain growth restriction are reported and discussed (23 refs).

Internal defects in steel castings (*Fonderia*, 1961, 10, Jan., 33-35) [In Italian].

Surface carbide formation in blackheart malleable iron C. T. Moore (*BCIRA J.*, 1961, 9, March, 244-262) Surface carbides, often found in pack annealed blackheart malleable iron, have a deleterious effect on tensile and bend properties. They are formed by Fe and CO, the reaction developing during annealing as a result of initial decarburization of the iron. The conditions are examined using low-C steel and Armco iron. The findings show that the surface carbides are formed during the second stage of the anneal and that they can be avoided by use of an inert atmosphere, by purging the furnace atmosphere with air between the first and second stage anneals or by the controlled introduction of air during the second stage. Simplified diagrams are presented which enable the effect of a given atmosphere at a given temp. to be predicted.—C.V.

A nuclear method for measuring the moisture content of foundry sand H. A. Burley, A. D. Block, and M. J. Diamond (*Gen. Motors Eng. J.*, 1961, 8, Jan.-Feb.-March, 2-6) The average moisture content can be measured by this gauge in a 3200 lb batch of sand to an accuracy of $\pm 0.05\%$ at a 3% level within 1 min. A 2-curve Pu-Be neutron source is used.—C.V.

Pattern problems British Steel Founders Assoc. (*BSFA Bull.*, 1959, 2, Aug., pp.23).

The part played by the pattern-maker in the moulding shop K. Oster (*Giesserei*, 1961, 48, (10), 296-297).

Gating and risering investment castings R. Rosenthal (*Foundry*, 1961, 89, April, 68-72).

The development and improvement of gating and risering for ductile iron H. O. Meriwether jun. (*Ironworker*, 1961, 25, Spring, 32-33) An outline of the gating and risering system now being used for ductile iron at the Lynchburg foundry is presented, with data on pouring time, effective sprue height, calculation of area of choke, runner size, ingate area, and of riser and riser connexion sizes.—S.H.-S.

The chill mould temper foundry as 'casting thermal unit' K. Stölzel (*Giessereitechnik*, 1961, 7, April, 113-115) The design and construction of a mechanical chill mould casting assembly in the form of a 'casting thermal unit'

is described. This assembly makes possible the moving-band completion of the chill mould temper casting from the melting up to and including the tempering process, within 24 h, thus exploiting optimally all conditions favouring graphitization.

The properties of core mixtures Z. Wertz (*Prz. Odlew.*, 1960, 10, (12), 333-340) Quartz sand used for making good quality cores should consist of round or rounded grains of such a size that the permeability of the mixture is not less than $100 \text{ cm}^4/\text{g/min}$. The -0.15 mm fraction should be rejected. When using coarser grain, application of special protective coatings is recommended. As the addition of the binders has many disadvantages beside strengthening the core the amount and the kind should be such as to produce the greatest effect using the smallest possible amount. When using clay as the bond the more fine its structure the smaller its effect on green strength, thus kaolinite clay is better in this regard than bentonite. The time of curing depends on the permeability of the mix, amount of moisture, kind of binder used, size and shape of the core, and finally the thermal conductivity and density of the mixture.

Eco core-drying ovens for Sulzer (*Brit. Eng. Transport*, 1961, 43, April, 290).

Effect of bismuth mould wash on soundness, structure and properties of grey iron castings M. J. Clifford (*BCIRA J.*, 1961, 9, May, 377-381).

Light structural design considered from the point of view of the founder. Part 1. Metallurgical prerequisites F. Kuhndörfer and R. Richter (*Giessereitechnik*, 1960, 6, Aug., 229-233).

Casting of crankshafts Z. Paz (*Prz. Odlew.*, 1960, 10, (12), 353-359) A review of methods used in USA, German, and Soviet Russia.

Teeming of base-plates for moulds in metal assemblies S. Ya. Skoblo (*Stal*, 1961, (5), 476).

The production of a bottom-half exhaust casting in cast iron L. D. Sparrow (*Brit. Found.*, 1960, 53, June, 283-286).

Development of the technology of the manufacture of turntables in machine-cast grey iron E. Bakovsky (*Giessereitechnik*, 1960, 6, Aug., 238-240).

A core binder with synthetic BALTOL resin S. Kowal (*Prz. Odlew.*, 1961, 11, (2), 55-56).

Influence of the backing-up material in shell moulding M. Klemmer (*Giesserei*, 1961, 48, May 18, 291-293) Old backing-up techniques with binder-free sands in the case of shell moulding were discussed and it was concluded that no technically-applicable effect on the structure of a cast item is obtained by backing up the shell with a heat removing coarse mass. The use of heat conducting metal oxides and metal powders as shell material seems to affect the structure of the casting.—M.L.

The use of plastic moulds in castings. III D. Iturrioz (*Met. Elect.*, 1961, 25, 135-146).

The influence of black-wash on the solidification of chill-cast grey iron E. Bakovsky (*Giessereitechnik*, 1960, 6, Dec., 353-358) The effect of cooling rate on the solidification of white iron is discussed with a view to avoiding white iron during production of chill-cast grey iron. It is shown that the final mould temp. can be increased by a suitable mould wash, thus ensuring solidification of the grey structure for a given chemical composition. Further work is suggested.—R.P.

The measurement of the cooling process in cast iron H. Grossmann and R. Richter (*Giessereitechnik*, 1961, 7, April, 115-118) The design and operation of thermocouples for the measurement of the course of casting cooling processes. The technology described enables prevention of disturbances and errors of measurement.—M.L.

Surface defects on shell moulding castings J. A. Behring and R. W. Heine (*Fonderia*, 1961, 10, (4), 145-153) [In Italian].

Defects in steel castings R. A. Bousted (*Fonderie Belge*, 1961, 31, April, 97-105) [In French].

The scientific organisation of foundry work J. J. Fernandez Fernandez (*Fonderia*, 1961, 10, (4), 155-166) [In Italian].

Contribution to the improvement in the

technical relations between foundrymen and designers (*Fonderia*, 1961, 10, (4), 129-137) [In Italian].

VACUUM METALLURGY

Vacuum technology T. Thorley (*J. B'ham. Met. Soc.*, 1961, 41, March, 3-14) A brief review. The practical aspects are summarized. The headings covered are, pumps, ultra high vacua, pressure measurement, leak detection, and design and maintenance.—C.V.

Vacuum treatment of molten steel F. Harders, H. Knüppel, and K. Brotzmann (*AIMME, Proc. OH Conf.*, 1960, 43, 145-157) The authors describe the Dortmund-Hörder Hüttenunion (DHHU) vacuum-degassing process, and review the operating experience to date. Some of the improvements in quality and steelmaking practice obtained with the process are given.—G.F.

Progress in steelmaking. Specialty producer modernized melting shops Midvale-Heppentall Co. (*Steel*, 1961, 147, April 3, 90-93) The use of vacuum remelting furnaces in increasing overall output of quality stainless steels and superalloy ingots is briefly discussed.—S.H.-S.

The casting process by vacuum degassing (v). Casting equipment of vacuum degassing in production scale T. Teijima, K. Yoshikawa, K. Ebihara, and K. Nagano (*Rep. Inst. Phys. Chem. Res.*, 1960, 36, (3), 296-304).

Thermodynamic considerations on desulphurization of cast iron in vacuum melting R. Ohno (*Sci. Rep. Res. Inst., Tohoku Univ.*, 1960, 12, Aug., 353-367) [In English] From studies of Fe-S, Fe-C-S, Fe-Si-S, and Fe-C-Si-S systems *in vacuo* relationships between desulphurization and the concn. of C and Si in the last three are explained on a phase-rule basis. Theoretical data are compared with experimental for an Fe-C-S alloy melted in graphite (22 refs).—K.E.J.

Modern industrial furnaces and their use in the wire industry K. Fritz (*Draht*, 1960, 11, Sept., 617-621).

Vacuum die-casting H. K. Barton (*Met. Constr. Mecan.*, 1961, 93, May, 409-423) [In French].

Descaling of steel by vacuum annealing without any introduction of reducing agents and the application of this method to the descaling and bright annealing of chromium nickel steel W. Herdieckerhoff (*Stahl Eisen*, 1961, 81, Feb. 16, 249-251) The author describes a vacuum annealing furnace in which not only the container but also the whole furnace is evacuated, i.e. temp. up to 1100°C may be used without any risk of buckling or tearing of the container during processing. The results obtained with this furnace and the industrial application of the process to the descaling and bright annealing of Cr-Ni steel is described and discussed.—T.G.

Experience gained in the descaling of hot plain-carbon steel strip in the vacuum furnace P. Werthebach (*Stahl Eisen*, 1961, 81, Feb. 16, 252) Tests for the descaling of hot strip of low-carbon steel in the vacuum furnace showed that besides grain growth as a result of recrystallization at the rather high annealing temp. of 1050°C the scale was not sufficiently reduced so that pickling was still required. Moreover, vacuum annealing had an adverse effect on the carbon and oxygen contents of the steel. The use of this process can therefore not be recommended to low-carbon steels.

REHEATING FURNACES AND SOAKING PITS

46in Mill soaking pits at Duquesne works M. B. Kruick (*ISA Proc.*, 10, (11), 1-13) This soaking pit is stated to be the first of its kind in the USA; previously air preheats averaged 700-1000°F while now 1100-1300°F is attained. Griscom, Russell, and Schack metallic recuperators were installed since there was no combustion air leakage (<1%), measurement of the combustion air on the cold side, longer life, they were more compact and gave fast recovery after charging. The layout of the plant, the equipment, and the instrumentation are discussed.—C.V.

Forged furnace design improves efficiency in

batch heating (*Metallurgia*, 1961, 63, May, 238-222) Tests performed by BISRA's plant engineering and energy division on a bogie-hearth oil-fired forge furnace at the works of Walter Somers Ltd, heating ingots up to 65 t are reported.—S.H.-S.

Heating furnaces changed over to natural gas fuel E. N. Dubinskii and A. E. Prikhozhenko (*Metallurg.*, 1960, (8), 31) [In Russian].

Press-furnace setup boosts forging capacity P. Olson (*Steel*, 1961, 148, May 1, 59) The 6000 t forging press and furnace installation of Eaton Mfg. Co. at Marion, Ohio, is described, and its production is compared with that of hammer units.—S.H.-S.

Combustion of natural gas during the non-oxidizing heating of steel in open-flame furnaces V. P. Nikiforov (*Kuznechno-Shtampov.*, 1960, (2), 26-29) The problem of preparation of the gas-air mixture before it enters the furnace chamber is of great importance. The solution of this problem would ensure: (a) the most rapid establishment of a stable equilibrium state in the furnace atmosphere, (b) the necessary gas temp. and a comparatively equal temp. field, and (c) optimum composition of the gas medium and its equal distribution throughout the volume of the furnace chamber.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The heat treatment of iron P. H. Dirom (*Fonderia*, 1961, 10, (4), 167-171) [In Italian].

Helpful hints for furnace buyers G. Hirshberg (*Indust. Heat.*, 1960, 27, Sept., 1846-1850).

Electric heat-treatment furnaces and equipment W. Scholl (*Elektrowärme*, 1961, 19, April, 159-168).

The use of a computer in heat-transfer studies M. S. Rhodes (*JISI*, 1961, 199, Nov., 258-261) [This issue].

Heat resistant steels and alloys used in the construction of gas hardening heat-treatment furnaces G. Pomey (*Rev. Nickel*, 1960, 26, Nov.-Dec., 147-156) The essential qualities required by materials used in the construction of heat-treatment furnaces are summarized. This explains the wide use of Fe-Ni-Cr steels or Ni-Cr alloys. Then their behaviour at high temp., in hardening, carbonitriding, nitriding, and oxidizing atmospheres is studied. This leads to the adoption of certain rules for the practice of treatment or in choosing the steels.

Effect of Zerolling on properties of modified type 347 stainless steel C. R. Mayne (*ASTM STP*, 1960, (287), June 30, 150-157) Zerolling is a method by which the austenitic stainless steels can be greatly strengthened and that heating to temp. up to 800°F results in additional strength. With the addition of Nb or Al or both, the strengths achievable are remarkably high. Procedure and test results are described.

Metallic thermal conductors for high temperature furnaces R. Kieffer and F. Benesovsky (*Jahrbuch der Electrowärme*, 1957, 217-229, preprint) The physical properties of Mo, W, Ta, and Mo silicide are examined from the point of view of their application as conductors in high-temp. furnaces. The behaviour of these materials in various atmospheres and in contact with refractories is dealt with (23 refs).

Heat treatment of rod and wire R. T. Merrell, E. F. Frederick, and G. R. Decker (*Wire Wire Prod.*, 1959, 34, Aug., 972-973, 1027) A brief, general description of the production and heat treatment of rod and wire at the Pittsburgh works of the US Steel Corp. (Columbia-Geneva Steel Division).—C.V.

Heat treating of finished wire and wire products G. B. Berlien (*Wire Wire Prod.*, 1959, 34, Aug., 976, 1030-1032).

A search for the optimum conditions for the heat-treatment of large forgings S. Ya. Skoblo (*Stal'*, 1961, (5), 476).

Investigation of chilled castings with spheroidal graphite E. Scheil and F. Weiss (*Giesserei. Tech.-Wiss. Beihefte*, 1961, April, 71-77) It was shown that in melts first slowly and then rapidly cooled, first large and then small nodules of graphite are formed, and their formation is due to two processes. In chilled castings the rapidly solidified white case-hardened layer contains small graphite

nodules and their formation can be suppressed by omitting the injection operation. This layer structure could be influenced by small alloying additions, B, Al, Li, Te.—M.L.

Case-hardenability as a criterion for case hardening steels H. U. Meyer (*Berg. Hütten. Monatsh.*, 1960, 105, Nov., 292-301) Previous as well as recent hardenability tests are discussed and properties obtainable for various compositions are given. It is concluded that hardenability can be used as a criterion for case hardening.—R.P.

The development and future of gas carburizing T. W. Ruffie (*Iron Steel*, 1961, 34, April, 142-145).

Induction carburization of Armco iron in liquid media A. Moszczyński (*Prace Inst. Mech. Prec.*, 1960, 8, (29), 42-48) Tests with petrol and ethyl and methyl alcohols were carried out and methyl alcohol was found to be the most satisfactory medium. Induction heating was used to heat the metal and cause the alcohol to decompose, the resulting nascent carbon bringing about the carburization. Compared with gas carburizing the case depth was found to be the same. The induction method, however, offers higher temp. and consequent speeding up of the process. Furthermore, the induction method allows carburization to be localized.

The mechanism of carbide solution during the austenitization of high-speed steels Z. Bojarski (*JISI*, 1961, 199, Nov., 267-271) [This issue].

Effect of carbide stringers on the distortion of die steels during heat treatment K. Sachs (*Met. Treatment*, 1961, 28, Jan., 31-36) The author, after pointing out that the presence of carbides lowers the coefficient of expansion of steel, illustrates how carbides inhibit the dilatations of the matrix. Warping effects due to variations in carbide structure are then considered and the article concludes with practical applications of the distortion test.—A.H.M.

Heat treatment and mechanical properties of light wagon wheels M. Yu. Shifrin and S. I. Stupel (*Stal'*, 1961, (2), 167-170) The lighter section can be heat-treated more rapidly with higher strength and ductility equal to that of standard wheels. Test pieces should be taken near the working surface.

New heat-treat lines for plate bank on growing alloy markets G. J. McManus (*Iron Age*, 1961, 187, March 9, 85-87).

Influence of heat treatment on mechanical properties of cast 10% chromium steels S. Drápal (*Hutn. Listy*, 1961, 16, Feb., 120-128) [In Czech] The results of research on the influence of carbon content, pouring structure, homogenization annealing, and different parameters of heat treatment of cast 13% chrome steels showed that carbon content and tempering temp. considerably influenced the mechanical properties. These steels were compared with steels of other carbon contents and the results at different temp. are described.

'Micron' precision taper roller bearings and their heat treatment J. D. Tyler and H. J. Tucker (*Efco J.*, 1960, 1, April, 2-10) The special characteristics of this bearing are discussed; the steel mainly used is BSS EN.31 this being normally obtained in the spheroidized, fully annealed condition; the complete treatment is: preheating 450-550°, neutral salt bath treatment 840-860°, isothermal quench in salt 180°, cooling and drying in still air, washing with warm water and rinsing with cold followed by dewatering in oil, temp. or stress relief 170°, primary grind and hardness test and stabilizing at 150°. The different steps are discussed in greater detail and several illustrations are included.—C.V.

Precise heat treating of high-strength, thin walled rocket cases (*Met. Treating*, 1960-61, 11, Dec.-Jan., 2) A brief description is given of the newly constructed electric furnace, capable of handling metal pieces 10 ft in dia. and 30 ft long, with a rated heating capacity of 2500000 BTU/h. The temp. range of the furnace is 400-2200°F and a tolerance of $\pm 10^\circ\text{F}$ is claimed.—A.H.N.

Through hardening of rails on the experimental industrial installation S. V. Makaev, S. V. Gubert, and D. M. Rabinovich (*Stal'*, 1961, (2), 156-159) Heat-treatment of carbon steel by quenching and tempering to strength

levels comparable with those of alloy steels is carried out successfully in the plant described.

The effects of heat treatment on the thermal expansions of some boro-silicate glasses and iron-nickel-cobalt alloys and their significance in their behaviour of glass-to-metal seals L. F. Oldfield (*Glastechnische Berichte*, 1959, 5, V16-251, reprint).

Treatment up hardness of high speed steel R. F. Harvey (*Steel*, 1960, 147, Oct. 31, 66) Mechanical working of M-2 steel during heat-treatment, by a process often called 'hot cold working', with increases in hardness and changes in micro-structure is briefly described.

How to select proper case depth for carburized and hardened gears R. Pedersen and S. L. Rice (*SAE J.*, 1960, Nov., 34-38).

Use of alloy pallets lengths base tray life in Ford heat-treating cycle (*Met. Treating*, 1960, 11, Dec.-Jan., 16) A load of 252 lb of steering-gear parts is carried in a tray, carburized at 1670°F, and then quenched in oil. Because of the thermal shock, cast trays failed, and these were replaced by trays fabricated from Type 330 alloy bars. It is claimed that the life of the tray is thus increased by a factor of three.

Heat treatment of bearings (*Iron Steel*, 1961, 34, March, 90-91) A completely automatic heat-treatment line for carburizing, annealing, hardening, and tempering has been installed by AEI-Birlee Ltd, at British Timken, Daventry East Works. This is described and illustrated.

Multiple-step heat treatment of railroad roller bearings in completely automatic continuous cycle (*Indust. Heat.*, 1961, 28, Feb., 248-260) The Timken Co.'s Columbus plant is described.

High-temperature carburizing. III. Furnaces for high temperature carburizing W. H. Holcroft (*Indust. Heat.*, 1961, 28, Jan., 40-52) Particulars are given of furnaces for high-temp. carburizing, viz. rotary, roller-hearth, conveyor chain, batch-type, and pusher furnaces, and of hot oil-quenching installations.

Carburizing and carbonitriding in exposed element furnaces C. H. Stevenson (*Indust. Heat.*, 1961, 28, Feb., 282-292) To avoid electrical leakage as a result of soot deposition, furnaces are operated at 6 W. The Ni-Cr elements are coated with enamel to prevent attack of the alloy by the furnace atm. Data on furnace design are given.—K.E.J.

Induction hardening (*Iron Steel*, 1961, 34, March, 105) An automatic induction hardening installation is now in use at British Oxygen Engineering, Edmonton. It is at present employed for case-hardening short shafts and through-hardening bushes, but eventually is to be used for a much wider range of components. It is of the valve oscillating type, the induction heater delivering rf power at a frequency of 250 kc with a max. continuous output of 30 kW. The shaft-hardening machine can handle shafts up to 4 ft long and rates and distances of traverse are variable so that the machine can cover parts of a shaft at different speeds. The quenching is described.—C.V.

The theory and practice of nitriding A. Goffey (*Eng. Elect. J.*, 1961, 17, March, 43-48).

On the nitriding treatment of high speed steel S. Koshiba, K. Tanaka, and A. Sumi (*Nippon Kinzoku*, 1960, 24, July, 429-432) [In Japanese] The optimum treatment was found to be nitriding (in the proprietary NS 350) at 500-570° for 30-60 min, and hardness and thickness of case were measured.

The decarburization of steel wire P. Fischer (*Wire Wire Prod.*, 1961, 36, March, 336-339, 383-385).

Induction hardening of diagonal-cutting nippers (*P.O. Elect. Eng. J.*, 1961, 53, Jan., 247-249).

Stresses in hollow cylinders made of cast iron with spheroidal graphite, after inductive surface hardening F. Bollenrath and R. Geziro (*Giesserei Techn.-Wiss. Beihefte*, 1961, 13, April, 79-84) Hollow cylinders—16 mm internal dia. and 45.1 mm external dia. made of cast iron with spheroidal graphite were surface hardened (to a depth of 1.5-5 mm) and the multiaxial stresses were determined by a suitable combined procedure of boring and turning. The data for axial, tangential, and radial components of the stresses are reported, together with the resulting comparative

stresses as a function of the case-hardening depth.—M.L.

For stronger missile cases ... decarburise! J. M. Lynch (*Met. Prog.*, 1961, 79, March, 78-81).

Annealing in hood furnaces with movable annealing hoods Braun-Angott A.G. (*Wire Ind.*, 1961, 28, March, 285-286).

Annealing pearlite blackheart malleable iron castings Ley's Malleable Castings Ltd (*Metalurgia*, 1961, 63, March, 115-116).

How Forst heat-treat long broaches D. Fishlock (*Metalw. Prod.*, 1961, 105, May 10, 78-81).

Forty foot long generator rotors heat treated in vertical furnaces (*Indust. Heat.*, 1960, 27, Sept., 1816-1824) At United States Steel's Homestead District Works, the rotors up to 60in dia. are heat-treated vertically in seven furnaces; the installation also has a quench tower and an upending cradle.—K.E.J.

Steel composition adjusted during open coil annealing through controlled gas-metal reactions Lee Wilson Engineering Co. (*Indust. Heat.*, 1960, 27, Sept., 1864-1870) Open-coil annealing is used to produce drawing-quality and tin plate-temper sheets. By adjusting the atm, the steel composition may be changed, and the process is in use for 'direct-on' enamelling steel. Other possible uses are to improve properties of silicon steel, to restore surface decarburization and to improve hardness and strength.—K.E.J.

Surface graphitization of a hypereutectoid iron-carbon alloy G. R. Speich (*Trans. Met. Soc. AIME*, 1961, 221, April, 417-419) A high purity Fe-C alloy (0.88% C, 0.095%Mn, 0.016%Si, 0.005%S, and 0.002%P) was used and specimens were heat-treated in a commercial hot stage modified for rapid quenching which permitted direct observation of the formation of surface graphite. A vacuum of 10⁻⁴ to 10⁻⁵ mm prevented oxidation or decarburization of the specimens. Specimens were austenitized for 30 min at 1100° and quenched to a series of lower temp. where they were isothermally transformed. Surface graphite was observed to form at 700, 750, and 780° but not at 825, 900, or 1000°. The significance of these observations is discussed and microscopical examination of the specimens at room temp. indicated that the rate of surface graphitization was markedly sensitive to the orientation of the austenite; the rates of graphitization on either side of a twin boundary were so different that in some cases the twinned area appeared completely graphitized while the untwinned area was completely free of graphite. In some instances where the bulk of the austenite grain was not graphitized, heavy graphitization was found in the thermal grooves of existing or former grain boundaries where the contour of the surface was altered. This is examined in some detail.—C.V.

The possible exchange of matter between furnace atmosphere and work in routine annealing of cold worked steels in protective atmospheres T. Schmidt and J. Wünnig (*Stahl Eisen*, 1961, 81, March 16, 361-366) From equilibrium diagrams for oxygen- and carbon-involving reactions the possibility of certain reactions taking place during the annealing of steel in protective atmospheres is discussed. Tests on bell-type and continuous furnaces showed that large deviations from equilibrium conditions in fact occur. The actual phenomena such as oxidation and decarburization are discussed. It is for this reason that more recently protective atmospheres have been used which do not contain reactive components but are inert towards the work.—T.G.

A stand-type thermocouple for monitoring the annealing of coils in stack annealing furnaces F. S. Astaf'ev and A. A. Lisogor (*Stal*, 1961, (5), 461-464).

Best heat-treatment for PH stainless steels D. C. Ludwigson (*Prod. Eng.*, 1961, 32, May 8, 32-34).

Plate heat treatment at Consett (*Iron Steel*, 1961, 34, April, 136-138) The batch type normalizing and tempering furnaces designed by Gibbons Bros. of Dudley are described, their layouts being shown. Their dimensions and operating data are provided.—C.V.

Preheating tension annealing and normalisation (*Dansk. Tekn. Tidsskr.*, 1961, 85, April,

81-86) The preheating temp. is determined by carbon content and welding elements favouring tempered elasticity, thickness of plate, and tension of current. Particulars of steels preheated are tabulated. Factors in and results of preheating are given. The course of tension annealing and the reasons for it and normalization conclude the article (14 refs).

The influence of the temperature and duration of hardening on the quench hardness of cast iron with laminar and spheroidal graphite formation H. Borchers and G. Haberl (*Giesserei Techn.-Wiss. Beihefte*, 1961, 13, April, 85-95) The hardness of cast iron with laminar and spheroidal graphite was investigated in dependence on annealing temp. and annealing duration after water- and oil-quenching. The influence of the annealing conditions on the C content, the correlation between the graphite and the bound C, and the correlation between the C content and hardness were determined by corresponding studies. The data obtained are reported.—M.L.

Quench side rails for hardness A. O. Smith Corp. (*Iron Age*, 1961, 187, April 27, 109).

FORGING, STAMPING, DRAWING AND PRESSING

Automated system forges parts without operator effort (*Iron Age*, 1961, 187, May 11, 116-118) A completely-automated forging press with associated equipment, at the Am. Forge Div. of American Brake Shoe Co., Chicago, is described in detail.

Development of forming technology in Czechoslovakia E. Škrabal (*Czech. Heavy Ind.*, 1960, (9), 2-4).

Automatic slug line for cold forging (*Metalw. Prod.*, 1961, 105, March 29, 60-61) Cold Forging Ltd, have installed equipment to prepared steel blanks of uniform mass and shape prior to cold forging. This forms part of the 'Colforg' set-up installed, serving the dual purpose of providing a cold forging service to industry and service as a demonstration unit.

Cold forging of steel Saarlaendische Werkzeug-und-Maschinenfabrik W. Notherfer GmbH (*Machinery Lloyd*, 1961, 33, Jan. 14, 29-31).

Cold forming of steels F. Griffiths (*Sheet Metal Ind.*, 1961, 38, Feb., 123-128).

Basic features of the cold forging process A. M. Cooper (*Met. Treatment*, 1960, 27, Dec., 480-486) The author classifies and describes cold-forging machines and then deals with the sequence of operations. The limitations of cold forging are then listed together with the materials suitable for the process. The article is concluded with considerations of design drawing and specifications.—A.H.M.

Economical use of cold-forged components H. D. Feldmann (*Sheet Metal Ind.*, 1961, 38, Jan., 8-13) The author discusses cold-forging from the point of view of economic production quantity. He describes typical series of operations for the production of different types of component, with particular reference to the 'Colforg' method, for which he quotes cost of equipment. It is concluded that by the saving in the cost of material the capital invested could be regained within months.—A.H.M.

New machines and equipment for the cold forging of steel—'Colforg' process H. D. Feldmann (*Draht*, 1960, 11, Aug., 478-481).

Technical developments in modern drop stamps and forging presses J. S. Byam-Grounds (*Met. Treatment*, 1960, 27, Nov., 439-444) The author discusses various aspects of forging press design. These include frame rigidity, ease of maintenance, overload, and the unit pressure loading. The article is concluded by a comparison between forging and screw presses.—A.H.M.

Cold deforming H. J. Merchant (*Met. Treatment*, 1961, 28, Jan., 14-18).

Applications of the oxy-acetylene flame in forging shops G. Papuli (*Met. Ital.*, 1960, 52, Dec., 883-890) [In Italian].

Alloy research: Naval rotor forgings (*Can. Mines. Research and Special Projects* for 1960, 1961, 1) Further work on a new Cr-Mo-V steel for naval steam turbines for use at 565° is being carried out. The first heat-treatment which includes tempering at 705° failed to give

a satisfactory combination of creep and impact properties. Reheat treatment included tempering at 675° and 690°. The former gave high creep strength but only borderline impact values while the latter gave the optimum combination of both.—C.V.

Pot broaching produces external forms J. R. Cypher (*Metals Prod.*, 1961, 105, Jan. 25, 59-62).

Cold-upsetting steels for the manufacture of heat-treated steel screws H. Wedl (*Draht*, 1960, 11, Aug., 425-428) The compositions and manufacture of screws by cold working are reviewed, and their properties are discussed.

Recent developments in chipless forming W. Bye (*Europ. Masch. Markt.*, 1961, 11, March, 18e-21e) The new techniques of explosive forming, fluid forming, tube-in-strip, extrusion, precision forging, and cold-forming are very briefly reviewed.—S.H.-S.

Moving chains replace shuttles in automated forming line H. Chase (*Iron Age*, 1960, 186, Nov. 10, 176-177).

Control of press-shop operations (*Sheet Metal Ind.*, 1960, 37, Nov., 799-807, 830) A unique system, recently installed at the Birmingham works of Fisher and Ludlow Ltd, for the control and analysis of press operations is comprehensively described. A description is given of the control equipment and examples given of down-time analysis, production information for management, and day-to-day and long-term planning and control. It is claimed that since the system was installed press down-time has fallen and operating efficiency improved.—A.H.M.

New cold pressing methods D. Gales and V. Dudas (*Met. Constr. Masini*, 1960, 12, (12), 1117-1123).

Materials for press tools A. C. Shaw (*Sheet Metal Ind.*, 1961, 38, Jan., 43-48) The author discusses tool materials under the headings of epoxy resin, zinc-base alloys, Al bronze, and tool steels. The development of these materials is considered and cost comparisons given. The author then deals with problems of lubrication during pressing and concludes by giving a set of basic rules for the successful application of tool steels to deep drawing.—A.H.M.

Some typical operations in the manufacture of slotted angle J. V. Harding (*Sheet Metal Ind.*, 1960, 37, Dec., 886-890).

Quantity production of clock springs D. Fishlock (*Metals Prod.*, 1961, 105, March 1, 54-56) Methods of operation at Smiths Alarm Factory, Wishaw, Lanarkshire, are briefly described and illustrated.—S.H.-S.

Production procedures at the Beacon Works of John Thompson Motor Pressings Ltd (*Sheet Metal Ind.*, 1960, 37, Nov., 793-798).

Production procedure at the Beacon Works of John Thompson Motor Pressings Ltd (*Sheet Metal Ind.*, 1960, 37, Dec., 870-885).

Sheet metal data sheet. 12. Production of blanks J. W. Langton (*Sheet Metal Ind.*, 1960, 37, Dec., 917-919).

Improvements in punches for cylindrical deep drawing J. F. Wallace (*Sheet Metal Ind.*, 1960, 37, Dec., 901-904) Various methods of improving the limiting drawing ratio are surveyed and a description given of a low-alloy steel punch, knurled over the whole drawing surface. High drawing ratios are claimed by using this punch.—A.H.M.

Installation for the preparation of steel blanks for cold forging Cold Forging Ltd (*Metallurgia*, 1961, 63, April, 189-190).

Performance of forging presses H. Stern and J. I. T. Green (*Proc. I.M.E., Preprint*, 1961, 3-18) The various factors contributing to the slowing up of forging presses are reviewed and appropriate adjustment, maintenance, re-design of valves, etc., are suggested to counter this. The importance of parallel development of manipulators is stressed and the controls of press and manipulator should be interlinked so as to develop automatic operation. Numerous factors influence the choice of drive but each case must be judged individually since it greatly depends on the nature of the forging cycle and the required performance.—C.V.

Durgapur—A Technical Survey. Wheel and axle plant (*Iron Coal Trades Rev.*, 1960, pp.218, 134-158).

A new cold forging press Cold Forging Ltd

(*Auto Eng.*, 1961, 51, March, 116-117) A British-designed and built press is described which has been specially developed for rapid stroking and multi-station tooling. The details relating to the Colforg Type P 300 and P 302 are given. The former has a working pressure of 200 t; the latter 400 t.—C.V.

Closing the ends of pipes with simultaneous electrical heating S. Ya. Skoblo (*Stal'*, 1961, (5), 440) A note from Zhdanov.

The upsetting of parts made from heat-resisting steels I. S. Petrov (*Obrabotka zharnoprochnykh splavov*, Moscow, 1960, 75-78) The possibility was established and the technological process evolved for the cold upsetting of bolts and rivets made from steels EI69, 1Kh189T, 38KhA, and others. The design was worked out for upsetting tools fitted with hard metals and also for hard-metal inserts for these tools.—A.I.P.

The production of accurate die forgings of blades by the hot-deformation method M. Ya. Kuleshov (*Obrabotka zharnoprochnykh splavov*, Moscow, 1960, 79-86) Factors studied include the technological process of producing die forgings of blades, the actual forging, heat-treatment of die forgings, and the useful life of dies. Western practice is reviewed and also new technological processes under development at Soviet research institutes.—A.I.P.

Conveyors link forging line R. H. Eshelman (*Iron Age*, 1961, 187, May 4, 90-92) Three press-forging lines replacing the former batch-processing system in the Chrysler Forge Plant at New Castle Ind., with resultant production advantages and economies are described.

Universal crank presses M. Zák (*Czech. Heavy Ind.*, 1960, (9), 30-35) The parameters of LU universal single-point, LUD universal double-point, high-speed double-point, and LUC four-point presses are given and discussed. The design of some of the main mechanisms is reproduced and automation has been kept in view in the layouts suggested.—C.V.

Forming at high speeds F. Hrazdil (*Czech. Heavy Ind.*, 1960, (9), 5-13) This paper is specially devoted to the study of the use of explosives. Diagrams are presented showing the relationship between the forming force, reduction and speed of cold extrusion for steel and aluminium, and the mathematics of the critical velocity are discussed.—C.V.

High-energy-rate forming of close-tolerance parts Convaire; General Dynamics Corp. (*Air. Prod.*, 1961, 23, March, 80-86) This is a generic name given to high-velocity, high-impact processes developed to shape new and difficult alloys; it includes explosive methods of forming. The process here dealt with applies the piston/cylinder principle the required forming pressures being obtained by gas pressure. Parts produced by this process are illustrated and discussed. An electromagnetic-energy unit, 'Magnopak', employs magnetic forces to form and fuse metals; the power developed is very great and the action takes place in millionths of a second. The electrical energy from the power supply is fed into and stored in capacitors and the concentrated electro-magnetic force creates a powerful magnetic field when released. To convert this into mechanical energy, it is necessary to dissipate the electric current rapidly enough to accomplish work in the short time during which the magnetic lines are flowing. Parts finished by this method are stated to save more than 60% in material, 50% in tooling, and 75% in machining. Complex close-tolerance forgings are produced literally to size; complicated extrusions are forced through a die; intricate shapes are formed.—C.V.

Explosive forming (*Air. Prod.*, 1961, 23, April, 122-123) A method of explosive forming, adopted by the Ryan Aeronautical Co. of San Diego, Calif., using epoxy-faced concrete dies to produce large components between 50 and 200 in dia., is described.

Explosive forging V. Philipchuk (*AMC Techn. Rep.* 59-7-694; PB 161457, 1959, Oct., pp.18).

The drawing of stainless steel and nickel chrome alloys Paroxite (London) Ltd (*Wire Ind.*, 1961, 28, March, 261, 286) Various experiments carried out in conjunction with Samuel Fox and Co.'s Stocksbridge wire

department with the object of finding a suitable lubricant resulting in an oxalate coating under the trade name of BX are reported with advantages claimed for the new method.

Viscosity of lubricating oils and their effectiveness during the drawing of steel strip V. I. Konopina (*Kuznechno-Shlampov.*, 1960, (12), 8-9) The effectiveness of lubricants was assessed according to the drawing force present during the die-forging of steel strip. Drawing force was determined on a die device, designed for drawing steel strip with a cylindrical punch. Hollow cylinders were die-forged from grade 08kp (rimming) VG steel discs 76 mm in dia. and 1.22 mm thick. Investigations showed that with an increase in the viscosity of 'gun' lubricant, thickened with talc, the drawing force is lessened during the die-forging of cylindrical parts, and the effectiveness of the lubricants is consequently increased.—A.I.P.

In-line processing of rod to wire for cold heading R. C. Rhoades (*Wire Wire Prod.*, 1959, 34, Aug., 949-951, 1016-1019).

Fundamentals of wire drawing. 1 C. P. Bernhoeft (*Wire Ind.*, 1960, 27, July, 693, 695-701).

Production of stainless steel wire G. C. Klingel (*Wire Wire Prod.*, 1959, 34, Aug., 954-957, 1028-1029) The necessity for quality and precision is stressed.

Effect of back tension during wire drawing on the drawing process and on the properties of the drawn wire M. Martin, H. Koch, and F. Fischer (*Stahl Eisen*, 1961, 81, March 16, 349-356) It was found in the studies that drawing force and drawing temp. decreased with increasing back tension. This effect increases with increasing drawing angle and increasing reduction in cross-section. The finished wires showed higher tensile strength for higher back tension, whereas reduction of area and bendability are reduced only slightly.—T.G.

An improved method of production for flattened strand wire ropes Larmuth and Bulmer Co. (*Wire Ind.*, 1961, 28, March, 281-282).

The development of the design of wire reels in Germany and other countries. Part II P. Grüner (*Draht*, 1960, 11, Sept., 606-612).

Some thoughts on the use of heavy weight coils J. W. Bleakley (*Wire Ind.*, 1961, 28, March, 269-272).

Reducing the percentage of rejects in the manufacture of wire rod for telegraph wire M. A. Tylkin, V. A. Nikitskaya, and G. N. Burkhan (*Stal'*, 1961, (5), 448-451) About 50% of the low-carbon steel rod for telegraph wire is rejected for failures in bend test or conductivity. This is traced to faults at the steel-making stage (composition) and to rolling faults. Degassing, slow cooling, and ageing as well as high-temp. tempering reduce the amount of rejects. The steel should contain not more than 0.09%C and 0.40%Mn.

A brief survey of wire rod defects—their occurrence and detection G. Earnshaw (*Wire Ind.*, 1960, 27, July, 681, 693-685, 706-707).

Experience in the cold extrusion of steel parts Yu. F. Filimonov (*Kuznechno-Shlampov.*, 1960, (12), 1-5) Results are presented of laboratory investigations and the introduction on an industrial scale of cold extrusion processes for six different tractor parts. Equipment and processes used are described, and quality indices are given of parts made from various grades of steel. Preparations are being made for series production of two of the parts.

ROLLING MILL PRACTICE

Formula for 'spread' in hot flat rolling L. G. M. Sparling (*Proc. I.M.E., Preprint*, 1961, 30-37) A mathematical approach, the formulae of Ekellund, Wusatowski, and Hill being compared. Tables are provided showing the results obtained with hot flat rolling and the comparison of the experimental and calculated results using the three indicated formulae these being compared with that now proposed.—C.V.

Durgapur—A Technical Survey. Rolling mill plant (*Iron Coal Trades Rev.*, 1960, pp.218, 95-120).

A study of conditions for speeding up the process of pressure treatment of metals S. Ya.

Skoblo (*Stal'*, 1961, (5), 440) A note from Zhdanov.

Measurement of rolling power and torque in hot rolling, and computation of the deformation resistance W. Dahl, E. Wildschütz, and J. Langer (*Arch. Eisenh.*, 1961, 32, April, 213-219) Rolling power and torque measurements were performed on three steels in the temp. range 900-1200°C, at 10, 20, and 40% deformation and at 5-100 sec⁻¹ deformation rate. The results are compared with the Sims theory and are discussed. The deformation resistance increased as a function of the deformation rate (13 refs).—M.L.

Wear resistant materials for the roller-train of a rolling mill I. F. Prikhod'ko, V. P. Fedin, and Yu. G. Ivanov (*Metallurg*, 1960, (8), 27-31) [In Russian] A series of experiments was carried out in 1948-59 testing the resistance to wear of cast iron rollers of varying composition faced with different alloys. A number of facing electrodes are specified. The iron used had the composition: Chilled: 3.2-3.4%C; 1.8-2.5%Si; 0.5-0.9%Mn; 0.3-0.8%Ni; 0.8-1.10%S; 0.17-0.25%P; Cr; 2.2-2.8%C, 0.25-0.35%Si, 0.4-0.7%Mn, 15-16%Cr; 0.7-0.9%Ni; 0.09%S; 0.25%P. Tables are given for hardness and corresponding service life in tons of metal conveyed.

Rolling grooved spring steel L. V. Andreyuk and Ya. B. Furman (*Metallurg*, 1960, (8), 20-23) [In Russian] Special rolls are suggested for the 300 mill at the MMK, which can also be used for a number of other purposes when a precise arrangement of rolls is required in an axial direction with no appreciable axial stresses.

Inland's new automatic slabber E. R. McGaughey and R. J. Beeswy (*Iron Steel Eng.*, 1961, 38, Feb., 105-125).

The throughput of blooming mills and its characteristic quantities P. Stoker (*Stahl Eisen*, 1961, 81, March 2, 284-294) The throughput of blooming mills is discussed and a simple formula developed incorporating weight of the ingots and frequency at which the ingots enter the mill. This frequency depends on the weight of the ingot—there is an optimum weight with respect to throughput—and the number of passes and, of course, on the layout of the mill. The throughput of a mill with a rolling force of 1000 t is presented graphically for a range of cross-section sizes.

The Austrian Alpine Monbau Company's new light section mill J. Hohenreich (*Acier, Stahl, Steel*, 1961, 26, May, 216-218) [In French] A new light section mill is now being installed at Donawitz in Austria. It comprises a continuous wire mill and a combined bar and rod mill. The steel structure of the mill shop is described in detail.

Improvement of the production of carbon steel rails S. Ya. Skoblo (*Stal'*, 1961, (5), 414) A note from Zhdanov.

Experience in the rolling of high-manganese rails P. S. Plekhanov, V. A. Koshkin, and I. A. Kritinin (*Stal'*, 1961, (5), 423-425) Successful rolling after a homogenizing anneal at 1050-1100° is described. Their quality as-rolled is satisfactory. Work on the treatment of the ends is still going on.

Experience with a universal stand of a rail rolling mill N. G. Nefed'ev (*Metallurg.*, 1960, (5), 29-31) [In Russian] At the Nizhni Tagil Metallurgical Combine, the rolling is carried out as follows: One two-high reversing mill (900 mill); two three-high stands (800 mill), and instead of the normal finishing stand, a universal four-high stand, with some special adaptations which are described.

Improving the rolling process and technical and economic indices in the manufacture of lightened sections S. Ya. Skoblo (*Stal'*, 1961, (5), 439-440). A note from Zhdanov and Azovstal'.

Assessing the reserves of power and energy in the rolling of rails on the 800 mill train S. Ya. Skoblo (*Stal'*, 1961, (5), 439) A note from Zhdanov. Uneven distribution of pressure among the rolls was found in the present rolling sequence and it is recommended that this be redistributed more evenly.

Investigating the special features of rolling shaped sections from special alloys S. Ya. Skoblo (*Stal'*, 1961, (5), 490) A note from

Zhdanov jointly with the Stalin Metallurgical Works. The necessary data for working out heating schedules has been determined and some experimental rolling of a high-Ti alloy has been done (No details).

Experience with the new groove for the locking collar of the 8-5-20 wheel on the continuous mill P. I. Kopytin (*Stal'*, 1961, (5), 425-428) The calculations for the 12-stage rolling process on a 15-stand mill are given. Successful continuous rolling is being carried out.

Quality control in sheet production English Electric Co. Ltd (*Metallurgia*, 1961, 63, April, 191-192).

Rolling with increased reductions M. M. Gorenstein and V. I. Pogorzelskii (*Stal'*, 1961, (4), 343-344) A discussion of previous articles by Murov and by Kozhevnikov and Shternov (*idem*, 1960, (9)). It is pointed out that practical conditions differ widely from those of laboratory studies. The use of smooth or of grooved corrugated or knurled rolls is debated and proper knurling is recommended for high reduction ratios.

The use of computers in works making flat-rolled products P. Bouchaud and R. Feroldi (*JISI*, 1961, 199, Nov., 262-267) [This issue].

High quality sheet steel G. Hans (*Technische und Wissenschaftliche Berichte der August Thyssen-Hütte*, 1959, 1, 171-174) Methods of manufacture, specifications, properties, degree of roughness for various surface treatments, and material selection are reviewed briefly.

Modernization of Steelton's 20-in mill R. M. Weigle (*Iron Steel Eng.*, 1960, 37, Dec., 103-107) The new 28-in mill and a new 3-zone oil-fired reheating furnace installed at the Steelton plant of Bethlehem Steel Co. are described. Quality and yield have been improved and bloom sizes have been standardized.

Automatic preset screwdown control on Steelton's 28-in mill G. D. Nicolson (*Iron Steel Eng.*, 1960, 37, Dec., 108-113) The high-accuracy analogue system, permitting reduced manipulation by the operator combined with accurate screwdown control, is described, with a wiring diagram of the control system.

Selection of ingot and slab sizes for the modern strip mill W. W. Brown ('Flat rolled products. II. Semi-finished and finished', Interscience Publishers, 1960, 6, 23-39) The many factors are discussed; these are divided into separate groups. Formulae are provided for the calculation of ingot, slab and coil weights and data used to calculate weighted ingot weight, coil weight, yield and side reduction for specific mould size are given.—C.V.

Salient features of Armco Steel's new hot strip mill Butler Works C. H. Roberts and T. M. Kilgo (*Iron Steel Eng.*, 1960, 37, Dec., 83-96).

Precision rolling of flat products with small diameter work rolls M. E. Sendzimir (*J. Australian Inst. Met.*, 1960, 5, Nov., 187-200) The author describes in detail the Sendzimir planetary hot-strip mill and Sendzimir cold-strip mill, discussing the rolling theory in each case and covering their fields of application. The possibility of combining these mills with continuous casting of slabs in one continuous operation is mentioned.—G.F.

Some problems relating to hot-strip mill operations S. Hosoki (*J. Australian Inst. Met.*, 1960, 5, Nov., 201-208) A brief description is given of the hot-strip mill at Hirohata Works of Fuji Iron Steel Co., and difficulties experienced in the control of hot-strip surface finish and metallurgical properties are discussed. Particular attention is given to rolled-in scale and to problems associated with roll wear and temp. control.—G.F.

Analysis of operational factors derived from hot strip mill tests J. S. Ride (*Iron Steel Eng.*, 1960, 37, Nov., 77-90) A description of work carried out at the 56-in hot strip mill of the Hamilton Works of the Steel Company of Canada, with the aim of improving the productivity of the mill. The investigation, which is described in detail, and which was carried out mainly by the Syracuse University Research Institute, consisted of: accurate measurement of interstand strip speeds, and hence the actual drafts taken in each stand; derivation of an equation relating roll separating force to several rolling parameters for the

finishing train; calculation of the magnitude of forward slip in each stand between work rolls and strip; possibility of existence of slip between mating work and backup rolls; derivation of nomograms relating initial slab dimensions to rolling time on the reversing roughing mill, entry temp to the finishing train and head and tail end finishing temps after the continuous finishing train.

Instrumentation for hot strip mill test program N. S. Wells (*Iron Steel Eng.*, 1960, 37, Nov., 90-95) Instrumentation used in the programme described in the paper 'Analysis of operational factors derived from hot strip mill tests' (see previous abstract) is described.

Some special features of rolling with the rolls screwed down beforehand D. I. Suyarov, M. A. Benyakovskii, and L. G. Chubrikov (*Stal'*, 1961, (4), 336-339) The advantages of rolling under such conditions that the sides of the roll barrels remain in contact, and the effect of this on pressures and uniformity are discussed.

Complex mechanisation and automation of the finishing section of the continuous 300 strip mill P. I. Solov'ev and A. I. Merenkov (*Metallurg*, 1960, (11), 24-28) [In Russian] All the operations of the finishing section: coiling, transfer of the coils, binding, packing and delivery to store are fully mechanized and automated. Detailed description is given with drawings, layout and measurements.

Cold rolling mill expansion in New Jersey (*Engineer*, 1960, 210, Oct. 14, 251) The Athenia Steel Division of National-Standard Company of Clifton, New Jersey reports that the works can now supply flat steels, 16in wide and 0.072in thick to $\frac{1}{16}$ in wide and 0.0001in thick, in coils of 5000 lb. Flattened round wire $\frac{1}{16}$ in wide and 0.065in thick and 0.01in wide and 0.001in thick in 1000 lb coils is also produced. Processing speeds have been increased and parallel lines are used so as to make more effective use of equipment and manpower.

Cold rolling of tinplate on a continuous five-stand mill V. Kh. Faizullin and E. V. Shubin (*Stal'*, 1961, (4), 333-336) Modification of a mill designed for hot rolling for the cold rolling of tinplate by improved lubrication and cooling of the rolls increased output and reduced waste.

Tensiometer regulates cold mill strip tension (*Iron Steel Eng.*, 1960, 37, Dec., 204) A new indicating and regulating tensiometer for continuous direct measurement of strip tension in all types of cold rolling mill has been developed by Allis-Chalmers Manufacturing Co. The pressductor is used as the temp. measuring transducer, and tension can be measured over a wide range of strip speeds up to 800 ft/min with no moving parts except the rotation of the tension measuring roll.

The nature and origin of defects in billets used for rolling seamless tubes O. Pejčoch and M. Židek (*Hutník*, 1961, 11, (2), 59-74) [In Czech] Prevention and removal of defects are discussed in the light of the authors' own researches carried out in the Klement Gottwald Steelworks in Ostrava, Czechoslovakia.—P.F.

Manufacture of pipes from semi-killed types of steel, with a two-layer crystalline structure G. N. Oiks, S. A. Sharadzenidze, E. A. Svetlitskii, S. I. Malyshov, K. K. Lolua, and B. I. Mindlin (*Stal'*, 1961, (4), 304-307) The process is discussed and recommended. Quality remains the same with economic advantages.

Improving the technical and economic operational indices of the piercing stand of the continuous installation S. I. Orlov (*Stal'*, 1961, (4), 366) Various improvements in profile, the use of rotating mandrels and the use of a Cr-Mn steel are very briefly indicated.

Operation of a single groove plug mill A. Duennwald (*Iron Steel Eng.*, 1960, 37, Dec., 123-124) An outline of the operation of the Mannesmann automatic seamless mill making 4 $\frac{1}{2}$ -10 $\frac{1}{2}$ in casing and 4-10in linepipe, with reference to the reasons for the redesign of the plug mill and its main characteristics.

Mechanization and automation of the withdrawal of the piercing rods on the continuous pipe rolling mill M. G. Berdyanskii, I. I. Brodskii, V. P. Voinov, B. A. Gnilenko, V. A. Grinval'd, and G. Ya. Kryukov (*Metallurg*, 1960, (11), 30-33) [In Russian] Operations earlier carried out manually are now automated: return of trolley, gripping the rods,

attaching the hook on the endless conveyor, discard of the rods into the cooling tank, delivery of the pipes to a basket for transport etc. The individual mechanisms are explained and drawings with dimensions supplied.

Magnetic amplifiers in rolling-mill drives E. Fiebig and E. Joetten (*AEG Prog.*, 1960, (1), 67-73) The fact that these amplifiers have no moving parts, are not subject to wear, require no maintenance and allow potential-free summation of control signals is stressed and they are compared with transistor and thermionic valve amplifiers, etc. and the various circuits are shown. Experimental results show that a combination of a transistor and magnetic amplifier provides an excellent regulating unit with most satisfactory dynamic properties and it is suggested that this may supplant the rectifier system.—C.V.

Magnetic amplifiers for reversing drives K. H. Bielefeld and H. C. Heinzerling (*AEG Prog.*, 1960, (1), 93-96) Methods of operation, and the dynamic characteristics of servo amplifiers used in the reversing of universal, dc and ac motors are described.—C.V.

Some effects of specialization of rolled stock production O. Petržilka (*Hutn. Listy*, 1961, 16, March, 168-171) A survey is made of the development of production programmes in Czechoslovakian shape mills from 1937 to 1965. New innovations are described and others recommended to ensure future yield and operation.—R. S. F. C.

Consett Plate Mill (*Engineer*, 1961, 211, Jan. 27, 108-111).

The problems of good quality thin iron sheets I. Frantiu (*Met. Constr. Masini*, 1960, 12, (11), 1001-1008) The thin iron sheets produced in Rumania, were found to be poor in surface quality and low in mechanical and technical properties. Some improvement can be made by closer co-operation between producer and consumer, especially as far as knowledge of the former's possibilities and the latter's requirements are concerned. Existing mills can be improved by perfecting the annealing furnaces and by introducing cold-rolling.—M.L.

Lubrication at the hot rolling mill of Alcan Industries Ltd (*Sci. Lubr.*, 1961, 13, 17-21).

The continuous steel finishing rolling mill of Hoesch-Westfalenhütte A.G. (*Draht*, 1960, 11, Aug., 478-190).

Strip mill applies simulator to guide tin-plating line Industry Inc. (*Iron Age*, 1961, 187, March 16, 114-115) An electronic tin-line simulator, consisting of a circulating cell, a conduction reflow system, and a brilliance comparator, which sets parameters for plating current density, velocity of strip, electrolyte temp., reflow current, reflow cycle, quenching time, and brilliance of coating, is presented.

Rolls as guide elements in steel finishing and wire rolling mills E. Kummer (*Draht*, 1961, 12, Jan., 13-15).

Installation of the finishing trains of the Saint-Étienne works of Cie des Ateliers et Forges de la Loire G. Namy (*Rev. Mét.*, 1961, 58, Jan., 45-54).

Grinding opens new strip market E. B. Cleborne (*Steel*, 1960, 147, Oct. 24, 98-99) A combination of careful strip rolling with some new techniques in abrasive belt grinding, turning out thin-foil strip with tolerances of $\pm 3\%$ on 0.001 in thick material, with product holding thickness variations across width to less than 0.005 in to meet aircraft and missile specifications, with resulting production and economic advantages, is presented.—S.H.-S.

The production of cold rolled metals shows continuing progress in technique (*Tecn. Indust.*, 1961, 39, Jan., 49-54) [In Spanish] The operation of the Sendzimir mill is described in detail.

Applicabilities of diverse construction types of cold rolling trains H. Niederstein (*Blech*, 1961, 8, Feb., 84-91) The basic types of rolling mills concerned with cold rolling are reviewed. Especially considered were two-high, four-high, and multiple-roll rolling mills, covering their advantages and disadvantages, as well as the range where they may be applied.—M.L.

Review of 'The change of mechanical properties of metals and alloys in cold-rolling' by V. A. Tret'yakov and K. M. Radchenko, 1960, *Metallurgizdat*, pp.86 L. I. Polukhin, V. I.

Bairakov, and V. P. Fedin (*Stal'*, 1961, (2), 155).

Design with high strength cold rolled austenitic stainless sheet D. B. Roach and A. M. Hall (*Mat. Design, Eng.*, 1961, 53, Feb., 108-110) Properties of highly cold-reduced austenitic stainless sheet steel have been collected from various sources. AISI 301 (17Cr-7Ni), MicroMach, 301N (17Cr-7Ni), AISI 201 (Cr-Ni-Mn), and USS Tenelon and 17-5 MnV (both high Mn) steels are examined and discussed.

Cold rolling shapes a better disc R. Cogan and K. W. Stalker (*Steel*, 1960, 147, Oct. 31, 64-65) A cold-rolling technique, producing high strength discs in practically any material available in sheet form, with improved physical properties, reduced material waste, and production time, is briefly described.

Automatic gauge and tension control on cold reduction mills Richard Thomas and Baldwin (*Iron Coal Trades Rev.*, 1961, 182, Feb. 24, 401-402) This new system has been devised at Ebbw Vale. The inaccuracies attendant upon the use of a contact micrometer have been eliminated and an X-ray thickness gauge is now used. A schematic arrangement of this layout for a five-stand mill is shown. There is no automatic change in sampling time in line with the speed of the mill. In the event of faulty operation, mill control is left in such a condition that the operator, receiving warning of such a failure, can take over and carry on with normal manual operation which can override the automatic system at all times. This has now been in operation for some 10 months and further developments have led to the inclusion of automatic tension control between all stands.—C.V.

Cold rolling oils T. Berglund (*Jernkont. Ann.*, 1961, 145, (1), 25-45) In a study of some 70 oils of different kinds, their rolling, annealing, and cleaning properties are investigated. The influence of oil on the appearance of stocked material, the need for uniformity of successive batches of the same brand, analysis by spectrophotometry, and the Korman method of oxy-analysis are discussed.—S.H.-S.

Operation of a two-roll tube reducing mill with individual drive A. A. Shevchenko, G. I. Gulyaev, V. P. Anisiforov, I. G. Arutyunov, V. A. Yurgelenas, and V. P. Fedin (*Stal'*, 1961, (3), 251-256) An investigation of the working of the mill showed the necessity for very accurate setting of the roll speeds.

The use of divided strips in killed and rimming steel quality for the manufacture of longitudinal seam welded tubes K. Edelmann (*Neue Hütte*, 1961, 6, Feb., 81-87) [In German] The technology of precision steel tube and boiling tube manufacture is described. Test programme and segregation studies are discussed and the results of the tube testing are given.—R. S. F. C.

Calculations for steel tubing F. Kaplan (*Prod. Eng.*, 1960, 31, Dec. 26, 59).

Manufacture and quality of special steel tubes for high temperature and high pressure service K. Harada (*Sumi Met.*, 1960, 12, April, 459-469) [In Japanese] [No Summary].

Studies of a pilger tube cold-rolling mill W. Jäkel, H. Neumann, and W. Hofmann (*Neue Hütte*, 1961, 6, Feb., 87-91) [In German] Studies are made of different designs of pilger type cold-rolling mill rolls for a $3\frac{1}{2}$ in machine, designs are evaluated, and measurements are carried out. Measuring results are compared with those so far known and an evaluation of wear measurements of pilger tools is made.

The regulation of the piercer at the 400mm. tube rolling mill M. Adascalitei and C. Achitei (*Met. Constr. Masini*, 1960, 12, (11), 378-380) Examples of calculation are presented for the determination of the factors which govern the regulation of the piercer at roll mills for tubes of 400 mm length. The control is based on theoretical calculations, as well as practical data obtained in the course of operation.

Development and production technology of oil-drilling tubes of quality API E. L. Procházka (*Hutník*, 1961, 11, (1), 18-21) [In Czech] Production technology and properties are described. The composition of the steel is 0.35-0.42% C, 1.10-1.30% Mn, 0.30-0.40% Mn, 0.035% P (max.), and 0.040% S (max.). In properties it is equivalent to more highly alloyed tubes used for similar purposes, which

do however generally require no heat-treatment. In view of the shortage of Ni in Czechoslovakia the tube steel now developed is shown to be economical.—P.F.

Improvement of rolls and mandrels for piercing large ingots V. V. Shveikin, S. I. Orlov, and L. N. Karpenko (*Stal'*, 1961, (3), 256-259) Laboratory studies were carried out and a new profile for the rolls at the Chelyabinsk works was established. These are described and the calculations are given with an estimate of the advantages in operation of the new designs.

Review of S. I. Borisov's book: 'Production of pipes on automatic and on pilger mills' N. F. Ermolaev (*Stal'*, 1961, (3), 260-261).

Russians develop heavy helical rolling (*Metall. Prod.*, 1961, 105, May 10, 68-69) A machine installed at the Dzershinskii steel-works, which will roll stock of $4\frac{1}{2}$ in dia. by 13 ft 6 in long, is described. A tracer system operating from a template controls the rolls to produce profiles. A schematic diagram of the machine and a profile of the controls are presented.—S.H.-S.

Consett Iron's modern 4-high plate mill (*Iron Coal Trades Rev.*, 1961, 182, April 28, 896-900).

Wide strip at Rourkela (*Iron Steel Rev.*, 1961, 4, March, 27-28) The surrounding area is rich in mineral resources and the Barsua ore deposit is only 50 miles away in the so-called iron belt; the Rourkela iron ore is said to be one of the richest in the world. Coking coal is 20 miles distant and dolomite and Mn are equally close at hand. Details of the agreement with the German contractors are given for the erection and equipment of the plant which is to produce 720 000 t/year of plate, sheet, strip, and tinplate. The semi-continuous hot strip mill rolls 1300 t steel strip in coils or sheared strip in 8 h and the details are indicated.

The hot planetary mill for strip D. Ripamonti (*Met. Ital.*, 1961, 53, April, 157-160) [In Italian] The Sendzimir planetary strip rolling mill is ideal for producing hot rolled strip at the rate of 200-300 000 t a year for a limited market. For an annual production of 500-1 m, the large wide strip mills are, of course, the standard units. The planetary mill is an attempt to resolve the problem of producing strip in one pass from slabs of substantial thickness eliminating strip reheating and successive rolling as with the Steckel mill. There are at present four mills in industrial production two-strip uti 350 mm at Ductile Steel, Willenhall, England, and at Habershou and Son, Rotherham, one for strip up to 500 mm at Atlas Steel Works, Welland, Ontario, Canada, and one for strip up to 1000 mm at Sofini in Milan.

Automatic gage control on cold rolling mills at DOFASCO N. D. Stephens and A. Bisci (*Iron Steel Eng.*, 1961, 38, Feb., 93-98).

Cold rolling medium-width steel strip [at Brinsworth] (*Metallurgia*, 1961, 63, May, 213-216).

Mechanism of lubrication in cold rolling J. M. Thorp (*Proc. IME, Preprint*, 1961, 10-29) The speed effect in liquid lubricants is examined; it is found that there is a fairly sudden transition from boundary lubrication at low speeds where bulk liquid is squeezed out by the rolls, leaving only adsorbed monolayers of lubricant molecules, to a type of hydrodynamic lubrication at higher roll speeds; this is due to an entrapment of bulk lubricant at the entry plane in surface micro-crevices in the strip and rolls and there is a constant quantity of a particular lubricant taken up into the roll gap for each type of roll surface. Max. compression of these micropockets of liquid occurs at the neutral plane the strip being partly deformed by means of transmitted hydrostatic pressure but with stearic acid pretreatment, the surface irregularities are filled, the liquid is not entrapped, and speed effect is eliminated. The various aspects of this are examined and discussed and the question of special roll surface is considered.—C.V.

Manufacture and inspection of seamless steel tubes G. S. Marshall (*Quality Eng.*, 1960, 24, Sept., Oct., 142-151).

Production of thin-walled seamless tubes in England Yu. M. Matveev and Ya. E. Osada (*Stal'*, 1961, (5), 429-438) An account of the

principal British mills with the opinion that equipment, mechanization and automation are at a low level.

The production of tubes for pipelines by Lorraine Escourt M. F. Mallet (*Mines Met.*, 1961, April, 207-211) [In French].

Tape-controlled pipe bender (*Auto Eng.*, 1961, 51, March, 110-111) This unit has been designed by the General Machinery Division of the Baldwin-Lima-Hamilton Corporation; the 'Bend-O-Matic', which claims to be the first application of numerical control to a pipe-bending machine is described.

Automatic control of gauge in rolling mills R. B. Sims (*Jernkont. Tek. Rad.*, 1956, 19, (227), 85-106) After causes of gauge variations in flat rolling and design of mills to reduce it have been explained, an acceptable system of automatic gauge-control (AGC) is specified. An error-actuated closed loop regulator stable at all speeds should be used, the mean thickness of the strip should be held within the selected tolerances, the strip thickness should be controlled from end to end of the coil, the system should be safe and simple to operate, and in the event of a failure, hand operation should be immediately possible. The above points are discussed in the following sections.

Durgapur—A Technical Survey. Rolling mills electrical equipment (*Iron Coal Trades Rev.*, 1960, pp.218, 121-133, 120).

Straightening structural steel J. A. Edwards (*Iron Steel*, 1961, 34, April, 148).

Production of bent sections E. R. Shor and A. I. Merenkov (*Metallurg.*, 1960, (5), 26-29) [In Russian].

MACHINERY AND SERVICES FOR IRON AND STEELWORKS

Durgapur—A Technical Survey. Civil engineering design. I. General civil engineering works including site investigation. II. Coke ovens and associated plant. III. Ironmaking plant. IV. Steelmaking plant. V. Rolling mills, wheel and axle plant, central engineering maintenance department and foundry. VI—Power plant (*Iron Coal Trades Rev.*, 1960, pp.218, 34-37). **Civil engineering construction** (211-214). **General services** (179-193). **Work of the consulting engineer to the Government of India** (11, 13). **Standardization of the plant** (48-52). **Central engineering maintenance** (159-164). **Administrative buildings** (199-201). **Site organization and management** D. J. Bell (206-208).

The hydroelectric crane W. A. Morey (*Iron Steel Eng.*, 1961, 38, Feb., 99-104).

Steelwork for steelworks W. S. Atkins (*Building with steel*, 1961, 1, (6), 10-15) A general, illustrated, review.—C.V.

Crane design pays off in performance (*Steel*, 1961, 148, May 1, 67) An overhead crane design installed by Harnischfeger Corp. of Milwaukee at a Chanute, Kansas, cement plant is described. Four small motors are geared directly to the wheels moving the crane.

New crane has 'walk-in' girder (*Iron Age*, 1961, 187, May 4, 96) The equipment of the interior aisle of the Harnischfeger overhead-travelling crane's main girder with its pressurized passage way is briefly described.—S.H.-S.

Gantry crane for scrap yard (*Acier, Stahl, Steel*, 1961, 26, (2), 67-70) [In French] This article describes the design, construction, installation, and operation of a gantry crane by Anciens Etablissements Metallurgiques Nobel-speelman of St Niklaas, a Belgian firm.

The gantry crane used for servicing reheating furnaces K. Schmoll (*Fonderia*, 1961, 10, (4), 175-177) [In Italian].

Results of trials of a 14-MW flue-gas turbine H. Kruppe (*Stahl Eisen*, 1961, 81, March 30, 446-448) The trials of the first large, single-stage flue-gas turbine which is of the single-shaft design generating 14×10^6 watts are described. The plant installed at the Haspe works of Klöckner-Werke AG had completed more than 11 000 h of satisfactory operation by the middle of 1960.—T.G.

Improved grab construction S. Ya. Skoblo (*Stal*, 1961, (5), 403) A note from Zhdanov. Grabs for blast-furnace loading are mentioned.

Durgapur—A Technical Survey. Transportation (*Iron Coal Trades Rev.*, 1960, pp.218, 194-198). **The power plant** (173-178, 164).

Carrying 50-t ingot loads (*Oil Eng. and Gas Tur.*, 1961, 28, March, 402-403) A special articulated outfit, with an insulated container, employed experimentally at the Corby works of Stewarts and Lloyds Ltd, Northants, for the transfer of 50-t loads of heated ingots at a temp. of over 1000°C from the furnace at Open Heath to the soaking pits, is presented as the forerunner of a shuttle service of three similar vehicles to replace rail-track service for the purpose between the two plants. Technical data are given in some detail.—S.H.-S.

Infra-red heating system speeds thawing of hopper car loads at U.S. Steel's Youngstown works (*Indust. Heat.*, 1960, 27, Sept., 1857-1860) Directional heating is used to thaw frozen portions of loads of coal, coke, anthracite, dolomite, limestone, and sand.—K.E.J.

The choice of air fans G. Lanino (*Fonderia*, 1961, 10, (5), 207-215) [In Italian].

Maintenance of electrical power equipment J. G. Roberts (*Iron Steel Eng.*, 1961, 38, Feb., 126-131).

WELDING AND FLAME CUTTING

Universal welding installation V. P. Kolesnikov and S. M. Shlakovskii (*Svar. Proizv.*, 1958, (12), 31) This installation has been designed at the Kaliningrad works for expensive machines of all-welded construction with a large number of welded joints, e.g. longitudinal and annular seams in boilers and boiler diaphragms and shells. A short description is given of the installation and of the welding process.—A.I.P.

Interpretive report on welding of nickel clad and stainless clad steel plate W. H. Funk (*Welding Research Council Bulletin Series*, 1960, June, (61), pp.20) Characteristics of the bimetal products, procedures used for welding preparation, welding procedures available and their advantages and drawbacks, and difficulties encountered in welding clad steels are discussed. Inspection and post-welding treatment are reviewed (14 refs).

The metal-arc welding of stainless steels M. C. T. Bystram (*Edgar Allen News*, 1960, 39, Sept., 197-198).—C.V.

On replacing the corroded members in a truss bridge S. Sakurai and M. Tanaka (*Proc. of the Symposium on the failure and defects of bridges and structures. Japan Society for the Promotion of Science*, 1958, Dec., 1-7).

Machine for welding parts of different thickness from stainless steel F. A. Akselrod and M. P. Zaitsev (*Svar. Proizv.*, 1958, (12), 33-35) Technical data of the machine are presented and also a photograph giving a general view. Examples of two welded joints are shown although other shapes are possible; however the thinner part (thickness 0.1-0.5 mm) is always joined to the thicker part. The process is described in some detail.—A.I.P.

Modernization of the type MSM-150 machine for welding tubes of austenitic steels A. F. Kozhaev (*Svar. Proizv.*, 1958, (12), 27-29) This machine is used at a boiler works and the modernization described makes possible high quality welded joints in tubes of austenitic, low-alloy, and low-carbon steels. Fusion welding of austenitic tubes can be carried out at an upsetting rate of up to 80 mm/s.—A.I.P.

Automatic submerged-arc welding of austenitic steels using two methods of alloying A. Missikewitsch (*Zvaranie*, 1961, 10, (1), 18-20) [In Slovak] The relative advantages of using alloyed electrodes or alloyed slag in welding austenitic Cr-Ni steels, containing varying amounts of Mo, Ti, and Nb, are discussed on the basis of a literature survey and the author's own experimental work.—P.F.

Welding of reinforcing rods (*Can. Mines, Research and Special Projects Report* for 1960, 1961, 23).

Resistance welding of boiler tube systems J. Vintř and J. Červenka (*Zvaranie*, 1961, 10, (1), 10-14) [In Czech].

Welding of high-strength ship steels (*Can. Mines, Research and Special Projects Report* for 1960, 1961, 18) Twenty-five experimental ship steels were subjected to the weldability test using the cruciform method; the compositions were based on commercial HY 80 (USA) or OT 35 (UK) steels together with various

combinations designed to give good impact strength. Two sets of characteristics were found, (a) 12 steels that cracked severely in at least one of the two tests, and (b) no cracking, or very slight cracking in both tests, 13 steels. Further examination confirmed these findings and the behaviour is what would be expected from the composition.—C.V.

Skelp welder speeds tubemaking Jones and Laughlin Steel Corp. (*Steel*, 1961, 148, March 6, 72).

Welding of large pipes by the under-powder method Mennen (*Schweisstechnik*, 1961, 15, April, 43-46).

The welding of chrome steels H. Gerbeaux (*Mét. Constr. Métan.*, 1961, 93, March, 205, 207-209, 211, 213, 214) The study published in the two previous issues is concluded and discussed.—S.H.-S.

Welding tungsten or molybdenum modified 5%Cr steels V. Pilous (*Zvaranie*, 1961, 10, (1), 5-9) [In Czech] A study was made of the welding of 5%Cr steels containing 0.5%Mo or 1%W. Both steels were found to be equivalent from the point of view of welding technology; 5%Cr, 0.5%Mo electrodes alloyed in the core or coating are suitable.—P.F.

The welding of aluminized steel sheet T. M. Molossi and J. H. Nicholls (*Sheet Metal Ind.*, 1961, 38, Feb., 95-98, 146) Data are given on the resistance and fusion welding of aluminized steel sheet. Reference is made to spot welding, projection welding, seam and stitch welding, resistance butt welding, brazing, and argon-arc fusion welding.—A.H.M.

TIG welding joins copper to stainless J. M. Gerken and D. B. Kittle (*Metall. Prod.*, 1961, 105, March 1, 53) Copper and stainless steel can be joined by tungsten-arc inert-gas (TIG) welding, but the heat balance between the two metals needs careful adjustment, the object being to put most of the heat into the copper and fuse it to the stainless, rather than to melt the two metals together. The technique is described and exemplified.—S.H.-S.

Production welding of thin-walled pressure vessels T. J. Bosworth and D. S. Hemminger (*Weld. J.*, 1961, 40, Feb., 125-131) The procedure used for welding 18-7 PH and 4330 modified stainless steels is given. The special problems in the case of this work for the Bomarc missile programme, welding preparation, and techniques are discussed.

Welding of stainless steel. I (*Acciaio Inossid.*, 1961, 27, (6), 542-549) [In Italian] After an introduction on the choice of steel and methods of welding to be adopted the various welding techniques are dealt with in turn. They include oxyacetylene welding, arc welding in an atomic hydrogen atmosphere, arc welding with graphite electrode, arc welding with clad electrode, arc welding in an argon atmosphere, and submerged arc welding. The descriptions are well illustrated and the final section is devoted to the choice of electrodes.

Stainless steel fabrication at Windscale works E. H. Wills (*RISLEY-5006/74* 1953, Aug., pp.39; from *Nucl. Sci. Abs.*, 1959, 13, June 15, 1352).

Build-up welding of the worn clover-shaped spline of a spheroidal iron form roll I. Totz and W. Pirker (*Schweisstechn.*, 1961, Feb., 15, 22-23).

Experience on the welding of a high-temperature austenitic steel of great wall thickness W. A. Felix (*Arch. Eisenh.*, preprint, Paper from Internat. Discussion on long-time performance of high temperature steels, Düsseldorf, June 1960, pp.12) High-pressure valves for steam plant were constructed. The tests made are described and numerous illustrations and tables are given. Welds of G18B-AISI316 and G18B-G18B were examined and structures were investigated. Testing methods are discussed.

Flux materials for electrode coverings (*Weld. News*, 1960, April, 9-13; Oct., 8-13).

Spheroidal iron welding rod for gas welding (*Fonderia*, 1961, 10, Feb., 71-74) [In Italian] The characteristics and properties of spheroidal iron welding rods and their practical application are described.

Odd-ball problems? Lab will tackle them S. Erikson (*Metall. Bull.*, 1960, 23, (11), 33-37) Welding problems encountered and dealt with

by the laboratory of Elektriska Svetsnings AB of Sweden are described—with the aid of numerous micrographs.

Residual stress distribution in and around spot welds W. Bolton (*Brit. Weld. J.*, 1961, 8, Feb., 57–60) Stress determinations were carried out by measuring the deformation of a surface resulting from the release of stress on drilling a hole into the specimen to a known depth, and at a known distance from a spot-weld. The material used was FV520 stainless steel.

CO₂-welding of thin steel sheet products I. I. Zaruba (*Zvăr. Sborník*, 1961, 10, (1), 34–40) [In Slovak] The development and practice of CO₂-shielded welding of thin steel sheet in the USSR are described.—P.F.

Principles of manual electroslag welding O. Žákavec (*Zvăr. Sborník*, 1960, 9, (4), 462–470) [In Czech].—P.F.

Welding of large pipe couplings and melting of steel turnings by the electroslag method M. Zaruba (*Zvăr. Sborník*, 1961, 10, (4), 114–117) The technology of both processes is described.

Welded surface plates A. H. Kleinsorge (*Mech. Eng.*, 1961, 83, March, 52–54).

Weld-repair of a cracked cast-iron lid of a blast-furnace air-blower L. Kolek (*Zvăr. Sborník*, 1961, 10, (3), 75–78) [In Slovak].

Production equipment and methods for cross wire welding [Sciaky Electric Welding Machines Ltd.] (*Wire Ind.*, 1961, 28, April, 363–364).

Lathe redesign in welded steel E. Duesing (*Weld. J.*, 1961, 40, March, 244–248).

An aluminium back-up bar for automatic metal-arc gas-shielded welding C. M. Jenkins (*Weld. J.*, 1961, 40, March, 250–251).

A recent solution to the problem of stress relieving of welds under site conditions [induction heating] R. B. L. Tindall (*South African Mech. Eng.*, 1961, 10, Jan., 141–146).

On the metallurgy of electrodes for arc welding P. E. Wimmer (*Schweissen Schneiden*, 1961, 13, April, 140–146).

An austenitic electrode with controlled ferrite content for welding austenitic steels employed up to 650°C F. Richter (*Zvăr. Sborník*, 1960, 9, (4), 424–431) [In Czech] The development and use of the electrode, containing 1.5 to 5.0% of ferrite, is described, and its characteristics are discussed.—P.F.

Considerations on electrodes for electric iron powder welding D. J. I. Cobo (*Cienc. Tecn. Solda*, 1960, 10, 3(3231), 1–5) Development of the iron powder procedure is outlined, and factors influencing electrode properties are considered.

Evaluating crack-resistant electrodes for welding HY80 S. I. Roberts (*Weld. J.*, 1961, 40, March, 110-S–112-S) The method of selecting iron-powder-coated type electrodes in the range of 80000 psi yield strength of AWS classification E-9018, which are most suitable for welding on HY80 steel, is discussed, together with a method of grading, or predicting, which will be less crack sensitive or show less propensity to cracking in production use. Two series of weldability tests, one direct and one indirect, are presented, also a comparative electrode bend test; and results are evaluated.

Electrode V-59B for wear resistant hard surfacings J. Kučera (*Zvăr. Sborník*, 1961, 10, (3), 66–69) [In Czech] The development and application of the electrode are described. If correctly used, the weld metal contains comparatively large hexagonal carbides Cr₇C₃ in a ledeburitic/troostitic matrix. The composition of the weld metal is then: 3.3–5.5% C, 1–1.5% Mn, 2–2.5% Si, 24–27% Cr, 1.5–2% B, and the rest Fe. The electrode is alloyed in the coating.

Accessories and material for use in electroslag and submerged arc welding M. Mosný (*Zvăr. Sborník*, 1961, 10, (3), 71–75) [In Slovak] Fluxes, filler wires, etc. at present available or planned for introduction during the coming third five-year plan period are discussed.—P.F.

On the strength of welds in steel 10523.9 V. Gregor (*Zvăr. Sborník*, 1960, 9, (3), 277–303) [In Slovak] Mechanical tests, including experiments on fatigue, were carried out on welded beams of the steel, the latter containing 0.27% C, 1.04% Mn, 0.5% Si, 0.035% P, 0.023% S, 0.1% Cr, 0.09% Ni and 0.12% Cu. The steel was found to be satisfactory, both from

the point of view of static and dynamic stressing; ageing was minimal. Mechanical finishing was found to improve the fatigue strength of welds significantly.—P.F.

Shearing forces attainable during spot welding of carbon steel sheet up to 6 mm thick (Conclusion) O. Becken and K. Havers (*Schweissen Schneiden*, 1961, 13, April, 127–135) Experimental data and results are presented, regarding shearing forces in spot welds, including an investigation regarding the effect of variables on results quoted. The relation between spot diam. and shear tension is discussed. Recommendations are made, particularly regarding welding conditions and testing so as to achieve a given spot diam. and shear force.—R.F.

Permissible gas concentrations in welding under carbon dioxide as protective gas W. Hummitzsch (*Schweissen Schneiden*, 1960, 12, Aug., 368–369; from *Die Berufsgenossenschaft*, 1959, Nov., 453–454).

The effect of impurities in CO₂ on the mechanical properties of welds made by the CO₂ method V. Kříž (*Zvăr. Sborník*, 1961, 10, (4), 107–109) [In Slovak].

Influence of impurities in carbon dioxide on inert gas welding Tin Ming Wu (*Schweissen Schneiden*, 1960, 12, Aug., 350–354).

Investigations on the electroslag welding process R. Müller (*Schweissen Schneiden*, 1960, 12, Aug., 354–368) Experimental results on the electroslag welding of the steels St 37, St 52, St 50 and 13 CrMo44 are reported and discussed.

Measuring the stress in the welded runner of a flat-ironing machine K. Silovský (*Zvăr. Sborník*, 1961, 10, (3), 69–71) [In Slovak].

Welding by friction J. Mandaus and J. Voboril (*Mec. Elec.*, 1961, 45, March, 51–57) [In French] Friction welding is a new method of hot pressure welding using the heat produced by rubbing the contact surfaces to be welded one of which, to give the most elementary example, is fixed and the other rotated. Aspects dealt with include development of heat during friction, the techniques of friction welding, and the machines used. Using this method pieces can be welded which could not be welded by any other method.

Electroslag welding with lamellar electrodes B. A. Kokh (*Lit. Proizv.*, 1958, (11), 3–7) With lamellar electrodes the most important parameters are the voltage in the slag bath and its depth. If they are altered there is a very marked effect on the depth of the fused area of the edges. A great increase in voltage or decrease in slag-bath depth can reduce the stability of the process. Therefore these parameters are strictly controlled. Other parameters are discussed.—A.I.P.

Considerations on the significance of mechanical tests and non-destructive tests of welding G. Moravia (*Rivista Ital. Saldatura*, 1961, 13, (2), 53–59) [In Italian].

Electron beam welder breaks size limit (*Steel* 1961, 148, April 10, 100–102) Electron beam welders are described which claim to fuse practically any weldable metal or alloy, even some ceramics and to grain refine, stress relieve, out-gas, cut, metallize, vacuum braze, or grow crystals.—S.H.-S.

How explosives weld metals D. E. Davenport and G. E. Duvall (*Iron Age*, 1961, 187, May 4, 83–85) Various methods of explosive welding, with data on a number of parameters, are presented.—S.H.-S.

Yield strength of E9018 weld metal W. L. Wilcox and H. C. Campbell (*Weld. J.*, 1961, 40, May, 193S–196S) An investigation was conducted to determine the causes of yield strength variations between user acceptance tests and the manufacturers' quality control tests of E9018 electrodes. Its results show the effect of using stringer heads as well as low preheat and interpass temp. on increasing the strength of the weld metal in both the as-welded and stress-relieved conditions.—S.H.-S.

Notes on the assessment of filler metals and fluxes G. M. A. Blane, J. Colbus, and C. G. Keel (*Weld. J.*, 1961, 40, May, 210S–222S).

The effect of flux composition on the physico-chemical properties of slag forming in the oxygen cutting of stainless steels O. Sh.

Spektor (*Trudy Vniivotogen*, 6th issue, Moscow, 1960, 26–34).

Nature of the 'white strip' in welded joints made from heat-resisting pearlitic steels B. S. Kasatkin (*Issledovaniya po zharoprochnym splavam*, Moscow, 1960, 6, 223–226) Formation of the 'white strip' in the heat-affected zone of welded joints is linked with residual plastic deformation of the edges of the welded metal in the zone of initial heating, close to the A_{c1} point. Sections of white-strip metal exhibit a distorted crystalline lattice, an increased carbon content in the solid solution, and, evidently, nitrogen.—A.I.P.

Effect of low-frequency vibration on crystallization of welding-bath metal and on seam-metal properties V. L. Russo and P. N. Efimov (*Lit. Proizv.*, 1958, (11), 10–12) One important factor is specific-pressure impulses arising in the crystallizing metal. At a given value of the impulses, the ends of the growing crystals are destroyed: their splinters, being additional compulsory crystallization centres, lead to the breakdown and de-orientation of the structure of the original crystallization.—A.I.P.

The effect of weld flaws on the static and fatigue strengths of wrought iron chain links R. Jeffrey and J. R. Street (*Ministry of Power, Safety in Mines Research Establishment*, 1959, Res. Rep. 183, pp.27) The use of gamma radiography with radioactive isotopes for the inspection of the welds of traditional wrought iron chains has revealed that a large proportion contain flaws, mostly cavities. The experimental work described in this report was carried out in an attempt to obtain information that could be used to predict the effect of these flaws on the strength of the links.

Brazing missile and electronic components in dry hydrogen. I. H. E. Lewis (*Met. Prog.*, 1961, 79, March, 93–96).

Brazing shortouts for the B-58 D. R. Torgeson and J. J. Kenna (*Met. Prog.*, 1961, 79, March, 121–124).

Preliminary evaluation of ceramic adhesives for stainless steel L. E. Gates and W. E. Lent (*ASTM STP*, 1959, (271), Oct. 15, 37–46) Stainless steel honeycomb structures are being considered for wings and control surfaces of advanced missiles. The honeycomb assemblies must be bonded with an adhesive whose strength is satisfactory to temperatures of 1200 to 1500°. Previous work indicates that certain ceramic materials show promise in this respect. The paper describes tests and results.

Bonded metal to metal shear testing L. R. Lunsford (*ASTM STP*, 1959, (271), Oct. 15, 54–65) The factors affecting joint strength, the different specimen types, and the properties actually evaluated by each type are discussed in detail. These properties are compared with those of a bonded joint which allow failure to take place. The possibilities of predicting joint strength from basic material properties are discussed. The paper includes a discussion of the difficulties encountered in bonding titanium joints where the adherent strain is approximately twice that of steel or Al.

Tensile shear strength of adhesive bonded metals as a function of the rate of loading D. A. George, H. R. Butzlaff, and J. Mandel (*ASTM STP*, 1959, (271), Oct. 15, 47–53) An inter-laboratory test programme was devised by ASTM Committee D-14 on adhesives to study the effects of the rate of loading of the ultimate tensile shear strength of metal to metal adhesive bonded lap shear specimens. Two metals, three adhesives, two overlap lengths, and four rates of loading were studied. The tensile shear specimens tested at rates of stressing from 600 to 2000 psi per min showed very little change in strength due to stressing.

Low-temperature strengths of metal adhesives (*NBS Tech. Bull.*, 1960, 44, March, 41–42) Four types of structural adhesives were examined at temp. down to -424°F: 301-stainless steel and 2024-T3 Al-alloy were used and the method of testing is described. Epoxy-phenolic resins were used for the stainless steel sheets and the other types bonded the Al. The average ultimate strengths of the four types of adhesives at the lowest temperature were: rubber-phenolic 1065 psi, vinyl-phenolic 1650 psi, filled epoxide 2345 psi, epoxy-phenolic 3120 psi. It is stated that none of

these adhesives were formulated to withstand the particular test conditions.—C.V.

Metal-resin combinations, new materials for joining, filling and forming R. Rüstig (*Schweissen Schneiden*, 1961, 13, Jan., 12-16)

Material and thermal balance of oxygen cutting by separating the metal S. G. Gusov (*Svar. Proizv.*, 1958, (12), 13-17) Basically, all types of oxygen cutting (gas-flame, separation, surface, and electro-oxygen with metal/carbon electrode) are the same. A through cut in a metal part at its surface takes place as a result of two processes: melting of part of the metal by heat, and oxidation by the oxygen stream, preferentially in the liquid phase.—A.I.P.

Installation for the oxy-acetylene cutting of tubes Ya. A. Gal'perin (*Svar. Proizv.*, 1958, (12), 30).

An investigation of the oxygen-arc cutting of steel K. V. Vasil'ev (*Trudy Vniivotogena*, 6th issue, Moscow, 1960, 49-79) Subjects covered are oxygen cutting and electric heating, a review of existing methods of electric oxygen cutting, cutting by carbon electrode, using a following oxygen jet, manual cutting by steel rod electrode, and characteristics of the process of oxygen-arc cutting (18 refs).—A.I.P.

Concerning the melting coefficient during air-arc cutting I. S. Shapiro (*Trudy Vniivotogena*, 6th issue, Moscow, 1960, 134-135) Formulae are presented with which it is possible to determine the effect of the following technological factors: electrode diameter, current strength, and cutting rate on the weight output of air-arc cutting.—A.I.P.

Computer-controlled oxygen cutting machine installed in shipyard (*Metallurgia*, 1961, 63, May, 242) The world's first fully-automatic machine for cutting ships' plate to shape installed at the Wallsend-on-Tyne shipyard of Swan, Hunter, and Wigham Richardson Ltd is briefly described with operational procedures.

MACHINING AND MACHINABILITY

Machinability of metals L. Czaplicki (*Revue M. Tijds.*, 1961, 7, (1), 5-13) [In French].

Machinability of sintered iron R. S. Jamison and E. Geijer (*Progress in Powder Metallurgy, Met. Powder Ind. Fed.*, 1960, 16, 19-33) This problem has to be judged from tool wear and surface finish; neither of these are conclusive or independent of the other and both must be taken into consideration. The machinability of straight iron and graphite containing mixes is considerably improved by the addition of S and the effect of H_2 in the sintering atmosphere is considered. Cu additions give improvement and when enough has been added to provide Cu in the free unalloyed state the best results are attained. If Cu is present in 10% concentration, it is found that the addition of S will cause large dimensional change after sintering. Addition of P to C-containing mix compositions give excessive tool wear but in the presence of Cu this is much less marked. Pb improves the machinability of both straight iron and combined C-containing materials without changing the sintered properties. In conclusion it is pointed out that when it can be used an increased nose radius on the cutting edge and/or a lower feed rate results in a much improved surface finish.—C.V.

The machining of steel: A simple explanation of the principles and practice F. C. Lea and E. N. Simons (*Edgar Allen News*, 1960, 39, Sept., 193-196) A simple, practical review.

Theory of formation of chips O. Andersson (*Ajour*, 1960, 13, Nov., 164-166).

Fresh approach in machining takes aim on hard steels R. H. Eshelman (*Iron Age*, 1961, 187, April 27, 101-108) Trends in the machining of hard steels whose hardness approaches the hardness of the tool and various fields for their application and control are discussed.

Increased output when face milling heat-resisting steels and alloys F. P. Urvinskii (*Obrabotka zharoprochnykh splavov*, Moscow, 1960, 195-201) Investigations have been carried out to find ways of further increasing output by determining the optimum geometry of the cutting part of the tool, by establishing the optimum grade of hard alloy, and by studying the effect of the various elements in cutting on service life when working heat-resisting steel

EYalT(1Kh18N9T), heat-resisting alloys on a nickel base Eh467 and the alloy 'V', and also the titanium alloy VT2. Results are given.

A few comments on milling with sintered carbides J. Koloc (*Czech. Heavy Ind.*, 1960, (9), 26-29) A graph is presented showing tool life plotted against 12 sintered carbide tools of three grades, tough, medium toughness, and poor; as the degree of overall tool life efficiency depends on the percentage of cutting edge fragments, the discrepancies between the grades supplied by the different manufacturers were considerable but an interesting picture is presented. The setting up, and carrying out of the tests is described, together with their interpretation.—C.V.

From foreign practice on the working by cutting of stainless and heat-resisting steels and alloys A. Sh. Shifrin (*Obrabotka zharoprochnykh splavov*, Moscow, 1960, 202-206).

The workability of stainless steels during the turning, milling, and reaming processes Ya. L. Gurevich (*Obrabotka zharoprochnykh splavov*, Moscow, 1960, 214-221) Factors studied include the choice of materials for cutting tools, their wearing out and blunting, their geometry, cutting conditions for turning, geometry of milling cutters, and the effect of cutting conditions and of geometrical parameters of reaming on the cleanliness of the surface of existing apertures.

Workability of heat-resisting steels and alloys during turning, milling, and drilling with hard-alloy tools N. I. Reznikov (*Obrabotka zharoprochnykh splavov*, Moscow, 1960, 154-161) The basic effect of cooling media is a reduction of temp. in the contact zones swarf-cutting tool-manufactured part because of an increased passage of heat through the swarf and partly through the manufactured part. Other conclusions on cooling media are presented.—A.I.P.

Temperature distribution in the manufactured part and in the tool when working heat-resisting alloys and steels A. N. Reznikov (*Obrabotka zharoprochnykh splavov*, Moscow, 1960, 162-174) Theoretical formulae are presented for temp. distribution when cutting metals. Factors studied include temp. distribution in swarf, in the manufactured part, and in the cutting tool; heat flow and the thermal balance; temp. at the contact surfaces and methods for its reduction (8 refs).—A.I.P.

Ultrasonic mechanical machining. IX. 1. Machining speed and mixing ratio of abrasives. 2. Machining speed and geometrical condition of tool G. Nishimura, K. Yanagishima, and T. Shima (*J. Fac. Eng. Univ. Tokyo*, 1960, 26, Dec., 129-145) [In English] Machining speed generally increases with mixing ratio up to a certain limit, remains const., and then falls off. Good efficiency is obtained at mixing ratios of 0.5-1.0 a good qualitative relationship with machining speed is obtained by using a coeff. which takes into account both the cross-sectional pattern of the tool and the ratio of periphery to cross-sectional area.—K.E.J.

Languepinspark erosion machines Solar Weld Languepin Ltd (*Auto Eng.*, 1961, 51, March, 102-104) This method of machining has proved itself to be most economical in the forming of irregular-shaped holes in extremely hard materials and intricate die shapes can be produced with a minimum of difficulty. A new range of machines is reviewed.

Chemical machining (*Air. Prod.*, 1961, 23, April, 138-141) In the N. American B70 Mark 3 aircraft, because of the heat-resistant and corrosion-resistant alloys used, which preclude traditional methods of machining, chemical machining has been adopted for the manufacture of the honeycomb structure facing sheets and for many other operations on the airframe. Details of the process are presented and illustrated.—S.H.-S.

Tape-controlled mill checked quickly with new recorder Aerojet-General Corp. (*Iron Age*, 1961, 187, April 27, 112-113) Three types of test made once a month by a Brush Instruments Mark II recorder, for checking the tape-controlled milling machine of a rocket engine producer and reporting on its responses, ensuring that accurate servo response and proper control signals are present in the big mill's magnetic tape, are described.—S.H.-S.

CLEANING AND PICKLING

Scale on wire rod and its removal by mechanical means S. Garber and G. M. Sturgeon (*Wire Ind.*, 1961, 28, March, 257-259, 296).

Shot and grit blasting of structural steels D. C. C. Dixon and J. D. Thompson (*Building with Steel*, 1961, 1, (6), 30-32)

Cleaning diesel engine cylinder head castings (*Metallurgia*, 1961, 63, April, 173-174).

Republic installs 74-in sheet polisher (*Iron Steel Eng.*, 1961, 38, Feb., 147).

Electropolishing of carbon steels S. Acimovic (*Korrosion* 12, 1960, 169-171) [In German] A description of experiments carried out by the author on C steels of various compositions and heat-treatments, using two standard electrolytes ($H_2SO_4-H_3PO_4$ with and without dextrose) and a modified standard electrolyte ($H_2SO_4-H_3PO_4-Cr_2O_3-CrO_3-FeSO_4-CH_3COOH$). Satisfactory results were obtained.

Development and study of an acid bath for chemical polishing of V2A-steel. II. Polishing and rate of dissolution of the metal G. Schmid and H. Steinhausen (*Metallüberfläche*, 1961, 15, March, 65-70) The polishing of V2A-steel in HNO_3 solutions seems to follow the same mechanism as Cu alloys. The HCl addition is necessary only for the activation of the steel by forming NO^+ ions; the latter being formed especially in the viscous layer close to the metal surface, thus accelerating the dissolution of roughness peaks. **III. Viscosity and conductivity of the liquid film on the metal surface** (April, 97-100) Conductivity measurements have demonstrated that in the chemical polishing process of V2A steel in HNO_3 solutions the passivating film is removed by the HCl, and does not take part in the polishing process. Viscosity measurements have demonstrated that the sharp increase in the viscosity of the liquid film near the metal surface causes a steep decrease of the autocatalyst concentration, which favours the dissolution of the peaks.

PROTECTIVE COATINGS

Methods and materials for the preservation of small hardware items R. L. Murrens (*PB 161897, Final Rept.*, 1960, Aug., pp.22; *Rept. No. 60-2314; from US Res. Rep.*, 1961, 35, Feb. 10, 201) A review of tests on various coating methods is given.

The measurement of coating thickness by magneto-inductive methods J. Baczewski (*Prace Inst. Mech. Prec.*, 1960, 8, (29), 27-41) The purpose of the work was to investigate the suitability and limitations of the magneto-inductive method as applied to the measurement of the thickness of non-magnetic coatings on a steel base. It was found that the measured value depends on the variation of mains voltage, the type and thickness of the coating, the size of the base, the magnetic properties of the base, and the curvature of the base. Consequently the measuring instrument must be recalibrated for each surface. The accuracies obtained with various instruments are given.

Measurement of the thickness of electroplates by the electrolytic stripping method: Nickel over copper base P. B. Mathur and A. S. Lakshmanan (*J. Sci. Indust. Res.*, 1961, 20D, Jan., 16-18) A stripping cell for use with the anodic stripping method is discussed the improvements over an earlier design being the use of a rubber washer in the place of the former gasket giving improved current distribution and a conical shape. A solution of 0.8N H_2SO_4 and NaCl 1.8N is used and the measurements obtained are comparable to those with the BNF jet test and the microscope test.—C.V.

Measurement of the thickness of electroplates by electrolytic stripping method: stripping solutions for silver over copper, brass, mild steel, and nickel P. B. Mathur and N. Karupanan (*Plating*, 1961, 48, Feb., 170-172) A series of studies is reported and results are tabulated.—S.H.-S.

The nature, cause and effect of porosity in electro-deposits. VI. Note on a magnetic method of detecting corrosion currents F. Ogburn and W. H. Roberts (*Plating*, 1961, 48, Feb., 168-169) An experiment is described which demonstrates a magnetic method of detecting the electric current of a galvanic cell. The cell is

placed in a magnetic field, and interaction of the moving electric charges with the magnetic field results in motion of the electrolyte.

A contribution to the problem of ventilation in galvanic plants H. Henig (*Metallüberfläche*, 1961, 15, March, 81-87).

The oxidation of cyanide-bearing plating wastes by ozone N. E. Sondak and B. F. Dodge (*Plating*, 1961, 48, Feb., 173-180) Tests to establish the stoichiometry of the ozone-cyanide reaction in aqueous solution were performed in a semi-batch system by passing ozonized air through a cyanide solution. Results are presented as a series of graphs and tables. A similar plant using chlorine was designed and a comparative cost made of both methods, showing that, at present, the treatment of cyanide wastes with chlorine is the less expensive.—S.H.-S.

Chromium plating electrolytically without cracking R. Brugger (*Galvano*, 1960, 29, Sept., 500-504).

Electron-microscopical examination of cathode films obtained by galvanic chromium plating R. Weiner and C. Schiele (*Metallüberfläche*, 1960, 14, Dec., 357-359) A method is described for electron-microscopical observations of invisible cathode films, particularly those produced by reduction of chromic acid. Thin cathodic films (0.02μ) produced during Cr plating are shown to be non-porous whereas thicker ones (0.1μ) are porous.—R.P.

Coated steel sheet has 'built-in' corrosion control (*Ind. Fin.*, 1961, 13, April, 46-47) Brief details are given of the production of zinc-coated steel sheets at the Steel Co. of Wales Ltd, by the 'Dragonite' process, a continuous line treatment in which the sheet is prepared, electro-coated, then given a phosphating treatment and finally a chromate rinse. Preparation for painting is also considered.—G.F.

Nickel dip N. S. C. Millar (*Inst. Vit. Enamel.*, 1961, 11, March, 77-84) A brief general review.

A continuous automatic galvanizing line (*Mét. Constr. Mécan.*, 1961, 93, March, 231-233, 235-236) The galvanizing line for coiled steel strip produced by the Sendzimir-Armco process at the plant of the Société Anonyme de Construction et de Galvanization de Montataire (formerly the S.A. de Construction et de Galvanization de Denain-Lourches), with its equipment and operation, is described.

How zinc fights corrosion E. W. Horvick (*Ind. Eng. Chem.*, 1961, 53, Feb., 58A-60A).

Galvanized coatings (*Can. Mines, Research and Special Projects Report* for 1960, 1961, 26) Effect on the galvanized coating of Al, Pb, Cd, Sb, and Cu additions and temp. immersion time, etc., has been studied and the work is extended to the study of galvanizing behaviour of a variety of commercially-produced steel sheet materials. The results of this work are to be statistically evaluated.

Study on the spangle in the hot-dip galvanizing coating G. Mima, K. Kajikawa, and T. Kato (*Tetsu-to-Hagane*, 1961, 47, Feb., 129-133) The effect of Al and Sn is examined. The effect is produced by using electrolytic-grade Zn baths with 0.5% (or less) Al but the spangles formed give a weak contrast whereas if the concentration is >0.1 using Sn, a large and regular feathering effect is obtained. The formation mechanism is discussed and photomicrographs, etc., are presented showing the effects produced.—C.V.

Electrodeposition of iron-zinc alloy from the pyrophosphate bath V. Sree and T. L. Rama Char (*Plating*, 1961, 48, Jan., 50-56) The effect of variables on alloy deposition is presented in table form. The optimum operating conditions are shown and photomicrographs of deposits ($\times 700$) show the structure (21 refs.).

Semiconductor power rectifiers for sheet steel zinc plating E. R. Rogers and C. W. Yipp (*Elect. Times*, 1961, 139, Jan., 103-104).

Recent developments in the electrodeposition of zinc and cadmium T. E. Such (*Electropl. Met. Fin.*, 1961, 14, March, 79-83) After a brief survey of the comparative corrosion resistance of zinc and cadmium coatings, recent developments in zinc plating in cyanide zinc, acid zinc, and other zinc solutions, and tin-zinc alloy plating are discussed.—S.H.-S.

Colour finishing of galvanized steel sheet

panels [at National Steel Corp., Terre Haute, Ind.] (*Engineer*, 1961, 211, Feb. 10, 228-229).

Tinplate testing: Chemical and physical methods W. E. Hoare and S. C. Britton (*Tin Research Institute publication*, 1960, pp.55) Coating thickness (X-ray fluorescence technique, coulometric, and other methods), coating continuity tests and measurement of oxide film and oil film weight are discussed; performance tests, rust resistance, staining, lacquerability, solderability, and corrosion are summarized. Some 15 appendices deal in some detail with the various tests (24 refs.).—C.V.

Trend to thinner tinplate W. Richards (*Tin Printer & Box Maker*, 1960, 36, Aug., 5).

Plating steel sheet in molten tin A. Hrbek (*Hutník*, 1961, 11, (1), 21-24) [In Czech] Trends and developments in the manufacture of tinned sheet are surveyed, with special reference to the use of molten tin and cold tin-cladding of cold-rolled steel sheet.—P.F.

Growing uses of tin in application with cast iron (*Tin*, 1960, July, 169-170) The addition of Sn to cast iron is considered from the initial view that its presence caused brittleness to the present-day where it is found that ferrite is suppressed and pearlite formation is promoted without the formation of massive cementite. It is stressed that some of these later findings are still in the experimental stage but the results obtained are promising. The tinning of grey cast irons is discussed, the direct chloride method being used.—C.V.

Experimental oxygen-converter steel intended for tinplate J. Teindl, Z. Zdeňek, and A. Havlik (*Hutn. Listy*, 1961, 16, Feb., 103-107) [In Czech] The results of plate-classification following production, cupping tests, layer thickness, and layer porosity tests show that oxygen-converter steel is better than OH. The occurrence of minor faults is less and another technique such as widestrip rolling can be used to eliminate those remaining. Upon processing air-blown basic converter steel to tinplate with the air enriched by 27% oxygen, 25% of rejects occurred in one case during can trimming. With the oxygen-converter steel plate these faults did not occur.—R.S.F.C.

Cadmium plating of high-strength steels E. Meckelburg (*Blech*, 1961, 8, March, 193-194) The formation of a porous Cd layer on high strength steel to enable quick dispersion of brittleness causing H_2 was studied, determining the required conditions—elimination of the brightening agent from the normal Cd electrolytic bath, pretreatment of the surface with dry quartz and deposition of Cd at a current density of 7.6 A/dm^2 . The results of a series of experimental tests are reported.—M.L.

Investigations on the hot-dip aluminizing and colorizing of steel K. Wellinger and A. Schweizer (*Werkstattstechn.*, 1961, 51, Jan., 23-29).

Hot dip aluminized steel sheet J. H. Nicholls (*Corros. Prev.*, 1960, 7, Oct., 42-45).

Aluminum coatings on steel J. H. Nicholls (*Prod. Fin.*, 1960, 13, Sept., 87-90) Although Al does not confer the same degree of anodic protection to steel as does Zn, in marine and rural atmospheres an equivalent protective effect can be achieved and in 'chemical' surroundings it is preferable; it can also be used in contact with foodstuffs. The 1934 deposition system by means of Al-halides is discussed but is seldom used; vacuum deposition, colorizing and cladding are briefly summarized and hot dip aluminizing and spraying are especially discussed.

Electrodeposition of iron-tungsten alloys from the pyrophosphate bath K. I. Vasu and T. L. Rama Char (*J. Sci. Indust. Res.*, 1961, 20D, Feb., 81-82) Iron has been co-deposited with W from the pyrophosphate bath and optimum conditions have been established for obtaining satisfactory alloy plates with 17-56%W. A table of varying bath composition, cathode efficiency, and potential is appended.

Mainly metallurgy: Jubilee of the Metal Spraying Process T. H. Turner (*Engineer*, 1961, 211, March 3, 337-339).

A survey of recent developments in chromium plating S. W. Baier (*Metal Fin.*, 1961, 7, March, 89-95) (18 refs.).—C.V.

Chromium plating A. Logozzo (*Met. Fin. Guidebook-Directory*, 1960, 28, 300, 302, 304,

306, 308-312) A résumé of the solutions, mode of use, preparation of metals for hard chromium plating, the use of non-ferrous metals and 'stop-offs'.—C.V.

Porous chromium G. Dubpernell (*Met. Fin. Guidebook-Directory*, 1960, 28, 313-314) A brief description.—C.V.

Corrosion protection with decorative chromium E. J. Seyb (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 209-214; discussion 255).

Chromium plating of rifle barrels R. J. Girard and E. F. Koetsch jun. (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 199-206; discussion 253-254).

Endurance tests of metals: effect of chromium plating F. S. Williams (*PB 150877*, 1942, July, pp.52; from *US Res. Rept.*, 1961, 35, Jan. 13, 94) [No summary]

Experience in the operation and performance of dual chromium systems W. E. Lovell, E. H. Shotwell, and J. Boyd (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 215-225; discussion 255-256) The development of improved Cr electrodeposits is discussed and details of operating and testing procedures are given.

Decorative plating abroad A. C. Benning (*Met. Prog.*, 1961, 79, Jan., 113-116) The gradual transition from buffed Cu-Ni-Cr to the use of duplex Ni and crack-free Cr is noted. The methods followed in the UK, Germany, France and Sweden are considered.—C.V.

A study of variations in certain characteristics of bright nickel deposits with variations in bath temperature R. J. Clauss (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 105-109; discussion 240).

Plating of nickel, cobalt, iron and cadmium from sulphamate solutions R. C. Barratt (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 170-175; discussion 249).

Metallizing nickel powder W. B. Keyser (*Weld J.*, 1961, 40, March, 229-231) The feasibility of applying a corrosion-resistant coating to bare steel by metallizing nickel powder, with the techniques for prior preparation of base surfaces and the subsequent techniques for applying a nickel coating were investigated. It was determined that a vacuum-blast machine was suitable portable apparatus for preparing a metal surface for spraying, and a metal-spray gun gave satisfactory spraying of nickel powder.—S.H.-S.

Electroless nickel plating G. Fitzgerald-Lee (*Prod. Fin.*, 1961, 14, April, 60-61, 79, 99) A general review of the history of this process is given. Discovered in 1944 it, and later work, is covered in ASTM, STP 265 ('Symposium on Electroless Nickel Plating Catalytic Deposition of Nickel-phosphorus Alloys by Chemical Reduction in Aqueous Solution').—C.V.

The chemical reduction of nickel-phosphorus alloys from pyrophosphate solutions M. Schwartz (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 176-183; discussion 249-250) A new type of electroless nickel plating solution based on the complexing ability of pyrophosphates has been developed. It contains $\text{Na}_4\text{P}_2\text{O}_7$ 50g/l, $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ 25g/l, $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ 25g/l, NH_4OH to maintain pH=10-11 and is operated at 65-75°C.—A.D.H.

Porosity of nickel electrodeposits T. Zak and Z. Kwiatkowski (*Prac. Inst. Mech. Prec.*, 1960, 8, (30), 17-20) Ni electrodeposits on samples of carbon steel and cast iron have been tested for porosity using the ferroxy test. Electrodeposits on polished surfaces were less porous, yet the conductivity of the sample itself seemed to be also of some importance since even on the best polished samples of cast iron there was no significant drop of porosity of deposits of minus 100μ . Best results were obtained by applying mechanical and electrolytic polishing until a smoothness of 1 to 1.5μ was reached, using also additions of naphthalenetrisulphonate and a current density of 1 A/dm^2 .

Testing porosity, adhesion and hardness of nickel deposits W. W. Sellers (*Met. Fin. Guidebook-Directory*, 1960, 28, 607-611) A summary of tests, very briefly outlined.—C.V.

Corrosion and electrode potential studies of nickel chromium coatings A. H. Du Rose (*Tech. Proc. Amer. Electroplater's Soc.*, 1960, 83-89, discussion 238-239) Service and corrosion tests have shown duplex Ni (semibright

followed by bright) deposits are better than bright Ni. The outdoor corrosion weight loss for bright Ni foil is only slightly greater than that for sulphur-free Ni but the number of perforations is much greater for bright Ni. Electrode potential, galvanic and polarization data are given for bright Ni, sulphur free Ni and Cr.—A.D.H.

Electrodeposition of nickel-cobalt alloys A. J. Steiger (*Met. Fin.*, 1960, 58, Dec., 53-55) Recent Russian studies of the effect of bath composition, current density, pH and agitation on the electrodeposition of Ni-Co alloys are summarized.—A.D.H.

Some metallurgical aspects of hot-dipped tinplate J. Le Bas (*J. Australian Inst. Met.*, 1960, 5, Nov., 246-253) The author discusses the metallurgical control of the manufacture of hot-dipped tinplate at Port Kembla Works, giving details of the application, characteristics, and testing of the tinplate, and describing the defects which arise.—G.R.

Recovering tin from hardhead by selective oxidation of iron D. A. Wilson and P. M. Sullivan (*US Bur. Mines Rep. Invest.* 5756, 1961, pp.17) An oxidation method was tested successfully on melts of 2000 grams. Molten hardhead (near 1080°C) was blown with air to oxidize iron and leave tin in the reduced state, recovery of available tin being 96-98%, which contained 2 to 0.1% iron, which was reduced to 0.06% by filtration at 250°C. Iron oxide formed during oxidation was absorbed by a fluid flux cover composed of 43% silica, 17% burned limestone, and 40% fused borax.

Brass plating; bronze plating; arsenic plating N. Hall (*Met. Fin. Guidebook-Directory*, 1960, 28, 292, 296).

Cadmium plating J. C. Kosmos (*Met. Fin., Guidebook-Directory*, 1960, 28, 296, 298).

Control of hydrogen embrittlement by plating from cadmium cyanide baths, containing nitrate W. F. Hamilton and M. Levine (*Tech. Proc. Amer. Electroplaters' Soc.*, 1960, 160-165; discussion 246-247) The addition of nitrate and a proprietary organic additive to a cyanide cadmium plating bath greatly reduced hydrogen embrittlement of high strength steels. A cleaning procedure for use with the modified electrolyte and details of operation and control are described.—A.D.H.

Measuring the bond strength of sprayed metal coating by a tensile test method. [Studies on the bond strength and the adhesiveness of sprayed metal coatings. Part 1] Y. Mima (*J. Metal Finish. Soc. Japan*, 1960, 11, May, 168-74; from *Japan Sci. Rev. Mech. Elect. Engr.*, 1960, 7, Aug., 270) [No abstract].—C.F.C.

Measuring the adhesiveness of sprayed metal coatings with reference to absorbed energy by tensile test method. [Studies on the bond strength and the adhesiveness of sprayed metal coatings. Part 2] Y. Mima (*J. Metal Finish. Soc. Japan*, 1960, 11, June, 203-207, from *Japan Sci. Rev. Mech. Elect. Engr.*, 1960, 7, Aug., 270) [No abstract].—C.F.C.

Resistance to abrasion and thermal shock of metal-sprayed coatings S. Gebalski and J. Kaniesski (*Prac. Inst. Mech. Prec.*, 1960, 8, (30), 21-33) Ni-Cr-Si-B-Fe-C alloy alone and mixed with Al and SiC was sprayed on samples of mild C-steel using a Woll Colmonoy spray gun. Whereas using 15%Al there was an improvement of the resistance to abrasion, SiC additions tended rather to improve the resistance to thermal shock. The use of high-frequency currents for re-melting Al-SiC coatings is recommended as it results in coatings particularly resistant to high-temp. shock.

Some thoughts on the economic aspect of metal spraying W. E. Ballard (*Metal Fin.*, 1961, 7, Feb., 57-62, 70).

Laboratory and service evaluation of aluminized steel wire J. H. Rigo (*Corrosion*, 1961, 17, May, 245t-250t).

Finishing and protection by metallizing (*Usine Nouv.*, 1961, 17, June 1, 123) [In French] A brief description of the principles and applications of vacuum metallizing.

Corrosion protection of steel by the use of sprayed zinc and aluminium coatings T. K. Ross, E. L. Smith, and R. E. Hansford (*Korrosion*, 12, 1960, 172-177) [In German].

Sprayed-on metal replaces iron liners Metallizing Equipment Co. Ltd (*Mach. Shop.*

Mag., 1961, 22, May, 283-284) A method of two-stage spraying of cylinders for lightweight petrol engines in place of pressed-in iron liners for cylinder walls is described.—S.H.-S.

The adhesion of sprayed molybdenum R. T. Allsop, T. J. Pitt, and J. V. Hardy (*Metallurgia* 1961, 63, March, 125-131) A study of the interfaces between sprayed Mo and mild steel, cobalt, and Brightway bases is reported. Optical and electron microscopy revealed that interfacial layers were present between the Mo deposit and the steel, cobalt, and Brightway bases, the layer between the Mo and the steel base being indicated by the X-ray scanning analyser as probably Mo-Fe alloy. It is suggested that where Mo adheres to a smooth base, either or both of two mechanism of adhesion may operate: one the formation of an alloy layer between base and deposit, the other the infiltration of fused metal from the basal surface into the pores of the deposit.—S.H.-S.

Surface protection by fluidized sintering and flame spraying E. Gemmer (*Korrosion* 12, 1960, 159-161) [In German].

Further development of the metal spraying technique (VI) H. Reininger (*Metalloberfläche*, 1961, 15, March, 88-90) The spray soldering, spray welding, and corrosion protective films application processes are surveyed, discussing their characteristic features.—M.L.

Metal and heat resistant coating (*Genie Civil*, 1961, 81, May 1, 211-213) [In French] Metal coatings in very thin films obtained by cathodic or thermal pulverization on various supports are now increasingly used. A new technique of coating has been developed during recent years by using plasma torches which can reach 15000°C and applying thick metal coatings or refractory materials. This technique has made possible the production of highly efficient heat-resistant parts whose use has enabled rocket performance to be improved. The processes and properties are described.

Selecting conversion coatings for metal surfaces. I. Processes. II. Design considerations L. F. Spencer (*Mach. Design*, 1960, 32, Sept. 15, 154-160; Sept. 29, 123-127).

Contribution to the development of neoprene cladding for the protection of chemical apparatus M. Tixier (*Korrosion* 12, 1960, 155-158) [In German].

Further development of the metal spraying technique (vi) H. Reininger (*Metalloberfläche*, 1961, 15, April, 118-121) Corrosion protective coatings, scale prevention coatings, flame spraying of bearings, and repair and finishing of goods by means of metal spraying techniques are surveyed.—M.L.

Epoxyes give good service in well casing coating test W. R. Lambert (*Corrosion*, 1961, 17, May, 14).

Susceptibility of epoxy coatings to damage by fresh water immersion H. Moroson (*Corrosion*, 1961, 17, May, 28-29) The author discusses the resistance to fresh-water immersion of epoxy coatings with different curing agents. The coatings are found to blister consistently and a hypothesis on the mechanism of this failure is put forward.—G.F.

New coatings will solve out-door corrosion problems (*Ind. Fin.*, 1961, 13, April, 51) Brief details are given of the properties of 'D.L.P.C.' sheets to be produced by Dorman Long and Co. Ltd. The steel sheets are protected on both sides and all edges by a P.V.C. composition known as 'Vynasol', and will be particularly suitable for industrial roof cladding and siding.

Protection of steel against fatigue by non-metallic coatings B. Than and P. P. Benham (*Corros. Prev.*, 1961, 8, April, 52) Some mechanical and physical properties of 11 types of organic coatings were examined. It was found that some of the organics provided effective protection for steel against salt water at stress levels just below the air fatigue level but there was no clear correlation between the static tests and those for corrosion fatigue.

Corrosion resistance of enamels A. W. Murdoch (*Inst. Vit. Enamel.*, 1961, 11, April, 93-96) Different types of corrosion and the use of accelerated laboratory corrosion tests are discussed. The methods used in the laboratory of Ferro Enamels Ltd are essentially described and the difficulties encountered in reproducing long-term effects in a short period are indicated.—C.V.

The influence of chemical composition of enamel on its alkali resistance A. N. Revell (*Inst. Vit. Enamel.*, 1961, 11, April, 85-87) A simple method of measuring alkali resistance is proposed and a range of enamel frits is examined.

A glossary of terms (*Inst. Vit. Enamel.*, 1960, 11, Sept., Oct., 15-20; Nov., 29-32; Dec., 41-44).—C.V.

Ceramic coatings as high-temperature corrosion protection for metals A. Petzold (*Korrosion* 12, 1960, 207-211) [In German] Types of coating used, applications and resultant properties are discussed, with ferrous examples.

Vitreous enamelling in open fired furnaces (*Metallurgie*, 1961, 63, Feb., 77-78).

Glass on steel at Jury Holloware (*Products Fin.*, 1961, 14, May, 121-127).

Refractory coatings for high temperature protection J. V. Long (*Met. Prog.*, 1961, 79 March, 114-120) Base metals can be made more resistant to heat by conversion to 'composites'; this technique modifies the surface; the application of a refractory coat is also studied. The surface materials studied include glassy and matte ceramics, cermets, metallic and diffused metallic coatings. The techniques and results obtained are briefly shown.—C.V.

The occurrence of defects in the enamelling of cast iron H. Koerver and O. Hildebrandt (*Gießereitechnik*, 1961, 7, April, 105-108).

How to pick the right paint for the job J. E. Spector (*Metalw. Prod.*, 1961, 105, May 10, 72-74) A comprehensive quick-reference chart is presented covering surface preparation, selection, application, and drying of paints for a wide variety of uses.—S.H.-S.

Programme for new field tests to study the influence of accuracy of pretreatment, the extent of surface rusting etc. on the life of a paint on steel sheet. Standards for indicating degree of accuracy K. F. Trägårdh (*Korrosion* 12, 1960, 257-261) [In German].

Practical experience of the corrosion protection properties of zinc paints H. Sagel (*Korrosion* 12, 1960, 163-167) [In German].

The ion permeability of paint films K. Bartoň, D. Čermakova, and E. Beránek (*Korrosion* 12, 1960, 161-163) [In German] It is shown that paint permeability can largely be controlled by the addition of ion-active materials, and underpaint corrosion of rusted iron can be avoided.

Ionic conduction through varnish films B. W. Cherry and J. E. O. Mayne (*Corros. Prev.*, 1961, 8, April, 53) Ionic conduction through varnish films can take place by one of two processes; activated diffusion or aqueous conduction through the virtual pores. A long-oil pentaerythritol alkyd, a tung oil phenol-formaldehyde, and a polyamide-cured epoxide resin have been studied and the effects depend on the nature of the solution to which the film has been exposed. The first two mentioned carry negative charges while the epoxide with an isoelectric point of 8.8 pH has a positive charge below this value.—C.V.

Mechanism of breakdown of paint films on metals under immersed conditions C. P. De and V. M. Kelkar (*Corros. Prev.*, 1961, 8, April, 53).

GLAD SHEET AND HARD FACING

Diffusion coatings (*Mech. World*, 1960, 140, Sept., 392-393).

Chromizing P. A. Ceballos (*Acero Energ.*, 1961, 18, March-April, 55-63).

Several characteristic features in the deformation of hard chrome layers S. Kocanda (*Metalloberfläche*, 1961, 15, March, 71-72) The irregular structure of the hard Cr layer caused by static and dynamic loads was studied, investigating the micropores and microfissures and their dependence on the stresses applied. Attempts were made to correlate the phenomena with dislocation theory.—M.L.

Argon flush: key to fabrication of titanium-clad steel C. L. Kobrin (*Iron Age*, 1961, 187, April 27, 110-111).

POWDER METALLURGY

Iron ore reduction—kinetics and thermodynamics. I (*Indust. Heat.*, 1960, 27, Sept., 1876-1880) A discussion is presented of the optimum values of parameters in H_2 reduction

of iron ore, and of the operating needs for an iron powder production plant.—K.E.J.

Sintered nickel steels W. V. Knopp (*Proc. Met. Mold.*, 1960, 18, Sept., 55-61) The physical properties of reduced and electrolytic iron powder (0-9%Ni) are shown in ten tables and matching graphs are provided for the compacting pressures and sintering temperatures, the C content and tensile strengths being plotted.

Sintered nickel steels—the path to improved properties W. V. Knopp (*Progress in Powder Metallurgy, Met. Powder Ind. Fed.*, 1960, 16, 84-98) Reduced Fe-powder and electrolytic Fe-powder have been compacted at 50 t/in² at 2250, 2200, and 2050°F with Ni content 0-9% and dry H₂ atmosphere 1-3 and 3 h. The results are tabulated giving density, Rockwell hardness, tensile strength, yield strength, elongation, and dimensional change. Other tables show the results obtained with commercial Fe-powders, the effect of varying the compacting pressure, and of heat-treatment.

Application of stainless steel powder metallurgy W. L. Batten (*Progress in Powder Metallurgy, Met. Powder Ind. Fed.*, 1960, 16, 120-129) Metal-metal oxide equilibria (FeO, Fe₂O₃, Cr₂O₃, SiO₂, Al₂O₃) in H₂ atmospheres are studied. The curves show that in conditions to the right and below the lines reducing to the oxide is found while to the left and above they are oxidizing to the metal. Furnace design is considered and it is shown that higher production rates can be obtained with hump belt furnaces. Lubrication is discussed and numerous examples of parts produced from Type 316 stainless steel powder are illustrated.—C.v.

Stainless steel powder (*Pein. Fig. Ver.*, 1961, 37, April, 216-218) [In French] Stainless steel powders are used in the USA, not only in powder metallurgy but also as pigments for special high corrosion-resistant paints. To the 18-8 stainless steel powder have now been added other stainless steels during the past 12 years. This note describes their physical and chemical properties and composition, method of production, and applications.

Some sintered steels alloyed with copper and nickel—their properties and manufacture G. Findeisen (*Metall.*, 1960, 14, Oct., 995-998) Change in dimensions on sintering, tensile strength, elongation, density, and Brinell hardness were measured on sintered steels containing 2.5-7.5 wt.-%Ni, 5.0 wt.-%Cu (24 refs.).

The pressing and sintering properties of iron powders G. Zapf (*Powder Met.*, 1961, (7), 218-248) Details are presented of experience gained in testing some 20 different types of iron powders available in Europe for manufacture of sintered bearings and structural parts, grouped under four headings: reduced, atomized, comminuted, and electrolytic. The influence of the data thus obtained is discussed in detail.—S.H.-S.

Techniques for the evaluation of powders. I. Fundamental properties of particles and methods of sizing analysis H. Heywood (*Powder Met.*, 1961, (7), 1-28) The results of 30 years' research in the properties of powdered materials are summarized, with most of the conclusions applicable to metallic powders. The first section of the paper defines those fundamental properties that can be measured individually, and the second section describes the essential features for the sizing analysis of powders.

Techniques for the evaluation of powders. II. Bulk properties of metal powders P. R. Marshall (*Powder Met.*, 1961, (7), 29-43) Current methods of sampling, and determination of flow, apparent and tap density, particle size, 'fillability', and 'hydrogen loss' are reviewed. The general conclusion is that present tests are adequate, but that new tests more suited to powder usage should be devised.—S.H.-S.

Techniques for the evaluation of powders. III. Observations on compacts V. T. Morgan (*Powder Met.*, 1961, (7), 44-65) Tests to evaluate the pressing and sintering characteristics of metal powders are summarized under four headings: behaviour during pressing, properties of the green compact, behaviour during sintering, and the properties of the sintered compact. Specifications setting down standard testing techniques are described and reviewed with the principles involved.—S.H.-S.

Measurement of the surface area of powders by the BET method B. C. Lippens and M. E. A. Hermans (*Powder Met.*, 1961, (7), 66-81) Experimental aspects of the construction and use of a conventional BET apparatus are discussed, and improvements in the method of measuring adsorption and in the size of the equipment resulted in the development of the 'micro BET' apparatus described here, with simplification in the technique of measurement.—S.H.-S.

A comparative study of methods for particle-size, analysis in the sub-sieve range H. F. Fishmeister, C. A. Blände, and S. Palmqvist (*Powder Met.*, 1961, (7), 82-119) Eleven powders of widely different properties have been studied by 'single-value methods' and by 'size-distribution methods'. In addition, a series of WC powders has been studied to assess the reliable working ranges of these methods.

FERRITES, CERMETS AND CARBIDES

Steel-bonded carbides (*Air Prod.*, 1961, 23, April, 144-146) A new family of engineering materials, combining the machinability of steels with a wear-resistance approaching that of cemented WC is presented in four grades: two austenitic stainless-steel-bonded grades, offering machinability and corrosion, oxidation, and wear resistance; and two martensitic-steel-bonded materials, offering machinability, heat treatability, and extreme wear resistance in the hardened condition. Details of their properties and weldability to other materials are described.—S.H.-S.

An investigation of ultrasonic inspection methods for sintered powder metallurgy components E. H. Abbe and R. D. Korytoski (*Progress in Powder Metallurgy, Met. Powder Ind. Fed.*, 1960, 16, 5-18) The ultrasonic equipment used is described. Cast discs were ground smooth and parallel and scanned at 3 megacycles/sec.; absorption areas free of defects gave 2-3 decibels/cm. A radiographic print of a cast cylinder disc is shown alongside a chart giving the absorption data relating to it; the numbers upon this indicate the total attenuation in decibels between the transmitter and receiver at each data point but it is stressed that the absolute value of this data is meaningless and it is the relative values that supply the significant information. Continuous contour lines are loci of equal absorption and cross-hatched areas are shown which possess the greatest absorption. Comparison of the two diagrams shows a close correspondence. Further examples are also given. The attempts made to produce an ultrasonic camera are discussed and the modified techniques used to avoid astigmatism are described. It would appear that considerable progress has been made but much further work is still necessary.

What is steel-bonded carbide K. J. A. Brooks (*Metalw. Prod.*, 1961, 105, May 10, 65-67) Ferro-Tic C, a cemented carbide consisting of 33%TiC and 67% alloy steel (both by weight), combining the features of alloy steels, cemented carbides, and cermets, is described and its properties and uses discussed, with a comparative table which assesses it against tool steel, cemented tungsten carbide, and cast cobalt-base alloy. Further developments to improve its cutting qualities are pending.—S.H.-S.

Heat treatable steel-bonded carbides: New construction materials for tools and wear resistant components J. L. Ellis, E. Gregory, and M. Epner (*Progress in Powder Metallurgy, Met. Powder Ind. Fed.*, 1960, 16, 76-83) The significant characteristics of one grade of steel-bonded TiC are described and compared with those of cemented WC. The two outstanding features of Cr-Mo steel bonded carbides are that they can be heat-treated and when in the annealed condition they can be readily machined by normal techniques. Examples are given.—C.v.

A basis for non-destructive testing of cemented carbides W. O. Woods (*Progress in Powder Metallurgy, Met. Powder Ind., Fed.*, 1960, 16, 34-41) The equation $S = -nR + C$ (S =strength, R =hardness, C =a constant, n =the slope, and $n=m_1/m_2$) shows the linear dependence of hardness, independent of binder

content for a single class of carbide; B , the binder content is present in earlier equations but has disappeared during their solution. Examination of the curves shows a definite linear relation between hardness and strength; additionally it is found that at constant hardness, strength decreases as the minor carbide phase (TiC) content increases and the strength increases as the binder content increases. It is also found that as hardness increases, binder content decreases; more generally, the strength varies inversely as the hardness; this is to be expected from the negative slope of the equation. These principles are further analysed but it will be found that even the outline is sufficient to indicate the usefulness to the consumer and the producer since it can serve as a control check on the material.—C.v.

Stability relations of calcium ferrites: phase equilibria in the system $2CaO \cdot Fe_2O_3 - Fe_2O_3$ above 1135°C B. Phillips and A. Muan (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 1112-1118).

Numerical evaluation of functions occurring in a study of domain configuration in thin layers of $BaFe_{12}O_{19}$ A. J. W. Duijvestijn and B. P. A. Boonstra (*Philips Res. Rep.*, 1960, 15, Aug., 390-393) Two functions occurring in the theory of domain configuration in thin layers of $BaFe_{12}O_{19}$ are numerically evaluated and are graphically presented.—C.v.

PROPERTIES AND TESTS

Pedigree irons and steels for research (*BISRA, Summary*, 1960, (154), pp.3).

Research on the mechanical properties of metals (*NBS Tech. Bull.*, 1960, 44, March, 46-50) The results of various studies are briefly summarized: (1) it was found that individual grains acted independently of their neighbours and there was no evidence that grain boundaries or interaction with adjacent grains promoted cracking; the principle factor in fatigue crack initiation in polycrystalline Al appeared to be the resolved shear stress on the planes of easy slip in the slip direction. (2) Most fatigue cracks starting at the edges of a metal specimen are caused by the stress pattern rather than by lower fatigue strength at the edges. (3) If a transparent tape is applied to the surface of a fatigue specimen, bubbles form under this tape at about the same time that fatigue cracks are initiated; the bubbles are caused by gas liberated as the result of surface reactions and provide a useful method of studying these changes. (4) X-ray diffraction techniques determine the stresses occurring within the structure of a metal and the lattice strain can be ascertained by measuring the changes in interatomic spacing. (5) Using this technique on an iron specimen it was found that plastic deformation causes residual stresses to develop on a microscopic scale; the elastic and plastic behaviour of the ferrite lattice in a low alloy steel showed that the stresses exist in a relatively undistorted crystalline material being balanced by oppositely directed stresses either in distorted portions of the crystals adjacent to grain boundaries or in slip bands. The foregoing are merely indicative; many other examples are given.—C.v.

Growth of whiskers by chemical reactions C. R. Morelock and G. W. Sears (*J. Chem. Phys.*, 1961, 34, March, 1008-1009).

Plastic deformation of iron monocrystals B. Jaoul and D. Gonzalez (*J. Mech. Phys. Solids*, 1961, 9, Feb., 16-38) [In French].

The investigation of surface deformation L. Grunberg, D. Scott, and K. H. R. Wright (*Brit. J. App. Phys.*, 1961, 12, April, 134-140).

Concerning the theory of the weakening and complex alloying of steels B. A. Apaev (*Izledovaniya po zharoprochnym splavam*, Moscow, 1959, 5, 203-209).

The solid state W. J. Moore (*Ann. Rev. Phys. Chem.*, 1959, 409-434).

Measurement of dislocation movement in metals and affect on deformation G. Alers (*Indust. Heat.*, 1960, 27, Dec., 2604) Dislocations in neutron-irradiated Cu bars have been studied by a new technique involving extremely accurate measurements of the time taken for 10^7 c/s sound waves to be transmitted, and of the energy absorbed.—K.E.J.

Thermochemistry and thermodynamic properties of substances J. M. Sturtevant (*Ann. Rev. Phys. Chem.*, 1959, 1-30) A review containing 447 references relating to inorganic and organic substances and groups of organic compounds.

A study of the hot working of steels C. Rosard (*Met. Corr. Ind.*, 1960, March, 102-115; April, 140-153; May, 190-205) Torsion and tensile tests were carried out between 900 and 1200°C to determine the effects of deformation rate, temp. and of sudden changes of speed and temp. of deformation on the structure of 18-8, 25%Cr and 0.25%C steels. The effect of these variables on grain size and the application of the data to industrial operations are discussed. (33 refs.)—A.D.H.

Tensile tests at 250°C on Thomas, open hearth and electric steels alloyed with small amounts of phosphorus F. Erdmann-Jesnitzer, W. Parecht, W. Scholz (*Bergakademie*, 1960, 12, Dec., 679-684) The influence of increasing amounts of P, up to ~0.18%, on the occurrence of anomalies in the stress-strain diagram was investigated by tensile tests. No P influence was found, but the increase of tensile strength was found to be relative to the N₂ content. The results are discussed.

Centre notch-tensile test for rocket-chamber materials J. J. Warga (*Weld. J.*, 1961, 40, March, 1308-1345).

Properties of mild steel weld metal not revealed by the all-weld-metal tensile test K. Winterton (*Weld. J.*, 1961, 40, March, 106s-109s) A series of tests is reported and results are presented, with satisfactory deposits from low-hydrogen electrodes (E6018), and a suggestion is also put forward for the incorporation of a more realistic test procedure in the specifications.—S.H.-S.

Cryostat and accessories for tension testing at -423°F J. F. Watson and J. L. Christian (*Mat. Res. Stand. Bull. ASTM*, 1961, 1, Feb., 87-90) Apparatus is described using liquid H₂ as a coolant, comprising a liquid-level indicator, thermocouple, heater and extensometer for determining the mechanical properties of various materials at -423°F. Rapidity of testing, accommodation of large sized specimens, flexibility for testing different materials at several temp., safety features, sequence of operation, and performance data are reported.—S.H.-S.

Tensile cryostat for the temperature range 4° to 300°K R. M. McClintock and K. A. Warren (*Mat. Res. Stand. Bull. ASTM*, 1961, 1, Feb., 95-98) Details and performance of a cryostat for use with standard tension testing equipment, by which temp. between 4° and 300°K can be obtained, are presented. Including transfer losses, approx. 2½ litres of liquid H₂ are used in experiments at 20°K, and approx. 3 litres of liquid He at 4°K. Simplicity, portability and safety with liquid H₂ are claimed.

Notched longitudinal-bend specimens for evaluating armour weldments S. M. Silverstein, R. P. Sopher, and P. J. Rieppel (*Weld. J.*, 1961, 40, March, 113s-117s) A longitudinal-bend specimen was used to evaluate the toughness performance of high-strength armour steel weldments prepared with austenitic and ferritic grades 180 and 230 coated electrodes. Data from the bend specimens are compared with test results of H-plates made with same lot of base plates and with similar electrodes welding procedure and testing procedure are described and performance criteria and test results presented and discussed.—S.H.-S.

Some considerations on the results of torsion-relaxing tests upon four typical heat-resisting steels P. Brozzo (*Rev. Soudure*, 1961, 17, Jan., 44-49) A brief mathematical study is presented.—S.H.-S.

Investigation of plastic deformation on compression tests A. Pálvölgyi (*Koh. Lapok*, 1961, 94, Feb., 62-65) In the experiments described, the compression strength was determined by graphical extrapolation of stress values obtained from specimens of different heights after the same degree of deformation. The increase in compression strength was proportional to the increase in the log of deformation rate. In the hot compression tests, the stress-deformation curves showed a maximum, probably connected with the rate of recrystallization.

Metals under high speed loading J. S. Rinehart (*Mechanical Properties of Metals - A Short Course*, Pennsylvania State Univ., 1958, 235-261).

Impact testing of cast iron G. N. J. Gilbert (*Brit. Found.*, 1961, 54, June, 5-18).

Studies of load-time relationships in Charpy impact test S. Sakui, T. Nakamura, M. Omori, and S. Nunomura (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 85-88; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 176) Two recording systems were compared, one with a strain meter and the other with a piezo-electric crystal. Miniature test-pieces could be used to determine transition temp. Shifts of these during quench-hardening of mild steel almost paralleled hardness changes.—C.F.C.

Subsize Charpy correlation with standard Charpy C. H. Currell (*Mat. Res. Stand. Bull. ASTM*, 1961, 1, Feb., 91-94) A study is presented, using various specimen sizes, of Charpy V-notch impact properties of alloy steels over a range of temp. covering their transitions from ductile to brittle behaviour. Test data indicate linear correlation between the energy required to fracture standard-size and subsize Charpy V-notch specimens at the normal acceptance-test temp. of -40°C. A table comparing theoretical v. experimental data is appended.—S.H.-S.

On the breaking behaviour of perforated notched specimens in Charpy impact bending tests M. Tanaka, S. Umekawa, and W.-K. Chen (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 81-84; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 176) A new type of specimen which has a notch and a hole is proposed for Charpy impact test. This type of specimen is effective to distinguish crack initiation from its propagation stage. From breaking behaviours of specimens having different notch depths, it is observed that crack initiates at the root of a notch and develops to about 1-2 mm instantaneously. Specimens with U-shaped notches are recommended as standard.—C.F.C.

Comparison of Charpy V-notch and drop-weight tests for structural steels J. H. Gross and Y. Imai (*Mag. Soc. Naval Arch. Japan*, 1960, June, 252-57; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 176) [No abstract].—C.F.C.

Tensile properties of nitrogen-austenitized chromium steels E. T. Turkdogan and S. Ignatowicz (*JISI*, 1961, 199, Nov., 287-296) [This issue].

Tensile properties of austenitic stainless steels at elevated temperatures S. Terai and T. Abe (*Sumi. Met.*, 1960, 12, April, 428-437) [In Japanese].

Tensile properties of mild steel weld metal (*Can. Mines, Research and Special Projects Report* for 1960, 1961, 22) US, Canadian, and British electrode codes require the determination of mechanical properties of an all-weld-metal test piece. All-weld-metal test pieces were made with room temp. interpass control and without subsequent heat-treatment; this simulated conditions of structural steel-welding practice. Satisfactory deposits were found with low-hydrogen electrodes (E 6108) but other electrode classes (E 6010, E 6012, E 7024) produced deposits which failed to meet the ductility values specified by the codes. Deposited metals from all but the low-H₂ electrodes were characterized by fish-eyes and high H content. This poor ductility, possibly made permanent by the presence of fissures, may occur in the actual welded joint and the use of E 7010 and E 7024 electrodes rather than E 6018 may be considered dangerous in some plate structures.—C.V.

Properties of stainless steel sandwich using low-density honeycomb-cores H. Smullen and W. F. Roberts (*Weld. J.*, 1961, 40, Feb., 90s-96s).

Relations between structural constitution and strength properties of aluminium alloyed nitriding steels H. Tauscher and E. Stecher (*Neue Hütte*, 1961, 6, March, 146-150) Free ferrite is found in the heat-treated structure and it is shown that unequal distribution of Al results in a differential nitriding effect. On the nitriding steel, K 38 Cr AlMo6, the influence of ferrite on tensile strength and notched-bar

impact resistance is described as a function of the initial structure. The effect of free ferrite on pending fatigue strength is discussed, also influence of a nitride network on endurance.

A low temperature yield instability in iron J. B. Lean (*Aust. J. Phys.*, 1960, 13, July, 359-375) Polycrystalline specimens of a 0.07% C steel were tested in tension at liquid air temp. The magnitude of the serration on the stress-strain curve depended on the difference between the upper and lower yield stresses, on the rigidity of the testing machine employed, and on the applied strain rate. The mechanical stability of the tensile test during the yield point load drop is examined. The effect of adiabatic temp. increase in specimens deformed at low temp. in boiling liquids is also discussed.

The influence of temperature and strain rate on the flow stress of annealed and decarburized iron at subatmospheric temperatures Z. S. Basinski and J. W. Christian (*Aust. J. Phys.*, 1960, 13, July, 299-308) Uniform deformation was studied at temp. down to 78°K. The Cottrell-Stokes law is not obeyed in iron and the results can be explained in terms of the strong Peierls-Nabarro force in this metal.

The double-notched (V-V) bar tension-bending test T. W. Wlodek (*Can. Min. Met. Bull.*, 1961, 54, Jan., 72-86) A number of different types of double-notched tension-bending impact samples which have been considered and examined are described and discussed together with data on square arc flat impact samples. The tension-bending characteristics of as-cast, as-rolled, and as-machined surfaces are examined and analysed.—S.H.-S.

Some experiments concerning workability of type 316L austenitic stainless steel T. Yoshida, K. Matsunaga, K. Murase, and Y. Ono (*J. Japan Welding Soc.*, 1960, 29, June, 459-463; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 174) Mechanical and corrosion properties were measured after hot or cold straining. Hot bending showed some cracks and cold bending is preferable unless a temp. above 800°C is used. Solution heat-treatment after working is recommended.—C.F.C.

An unusual fracture G. F. Modlen (*Weld. J.*, 1961, 40, Feb., 65s-89s).

A new high speed impact tensile testing machine T. Tumura, S. Sakui, and M. Okamoto (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 95-98; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 175) A new high-speed impact tensile testing machine is described. It is of rotary disc type, its dia. 1800 mm, and weighs 2300 kg. Its impact velocity can be varied within a range of 5-140 m/sec. The machine is also designed to work at temp. from sub-zero to 1200°C.

Behaviour of pure iron under impact tensile loading S. Sakui, M. Omori, T. Mori, and K. Sato (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 89-94; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 175) [In English].

The impact test on lamellar cast iron D. Fortino (*Met. Ital.*, 1960, 52, Dec., 925-937) [In Italian] Impact testing has been carried out to ascertain whether this test can be used to judge the capacity of grey cast iron to withstand high dynamic stresses. It has been proved that a correlation exists between the breaking strain on the one hand and the chemical composition, tensile strength, and Brinell hardness on the other. Evidence has been found as to the influence of grain size and metallic matrix graphite quantity and type on the iron impact strength. It is concluded that the determination of grey cast iron impact strength is a useful supplement to both tensile and Brinell hardness tests.

Concerning the notch sensitivity of high-strength steels M. P. Markovets (*Ustaloost' Metallurg*, Moscow, 1960, 62-71) Certain criteria are put forward for assessing the notch sensitivity of high-strength steels. These were satisfactory under impact, static, and cyclic stresses. Notch sensitivity shows a complex relationship with metal strength. The opinion previously held that with an increase in metal strength notch sensitivity must invariably increase is false. Other conclusions are reached.

Concerning the notch-sensitivity of high-strength steels S. E. Belyaev (*Ustaloost' Metallurg*, Moscow, 1960, 72-79) Notch sensitivity of

high-strength steels is linked with ductility in the notch and decreases considerably with an increase in tensile strength. Steel with lowered ductility in the notch of 2-3% (tensile strength 145-200 kg/mm²) therefore exhibits increased notch sensitivity and steel with an increased ductility of 5-7% is not very sensitive.—A.I.P.

Fracture toughness of steel for pressure vessels H. Bernstein and G. C. Young (*Metals Eng. Quart.*, 1961, 1, Feb., 75-89) Initial toughness was related to notch-impact test value when thin-walled, high-pressure vessels were considered. Toughness was defined as the ability of a material to deform plastically in the presence of a notch of fixed geometry and the principal measure of toughness was energy absorption, although fracture appearance and transition temp. were also used; but though some of the data could be expressed in numerical form they had little meaning. The various aspects are considered in detail and numerous microstructures are shown, and it is found that the trends in fracture toughness as a result of micro-structural changes are similar to those exhibited in notch impact toughness. Study of these microstructures has yielded valuable information in the determination of fracture toughness and in the analysis of failures. It is stressed that much work in this direction still remains to be done and this contribution is only a progress report.—C.V.

Toughness of Mn-Si-Cr steels R. Šejnoha and F. Pavelka (*Hutn. Listy*, 1961, 16, March, 153-158) Mathematical-statistical analysis of test results of notch toughness was carried out on 19 laboratory melts of Mn-Si, Mn-Cr, and Mn-Si-Cr steels. Tests of notch toughness at +20°C were carried out after quenching and drawing 200 to 650°C/30 min/air and 500 to 650°C/30 min/water. Coefficients were calculated and put into equations. The applicability of Mn-Si-Cr steels for the region of low and high drawing temp. was evaluated.

Some factors affecting the notch toughness of steel weld metal K. E. Dorsch and R. D. Stout (*Weld. J.*, 1961, 40, March, 97s-105s) Effects of welding energy input, restraint during welding and weld metal composition on the notch toughness were investigated using both submerged-arc and gas-shielded consumable-electrode processes. Site additions were made to reveal the effects of single elements over a range for each welding process and effects are reported. Lowering welding energy input, reducing restraint, and adding nickel and manganese benefit weld-metal notch toughness. Additions of V, C, Mo, Cr and Si decrease toughness.—S.H.-S.

Comparative study of the notch impact strength of differently heat-treated carbon steels G. Altmeyer and A. Peiter (*Materialprüfung*, 1961, 3, April, 20, 147-155) The notch impact strength of a steel was plotted against the term by means of three characteristic values, choosing the transition point with the co-ordinates $\alpha_k \bar{u}$ (half of the high level energy) \bar{u} (the corresponding transition temp.) and the slope $\tan \alpha_k = \Delta \bar{u} / 10^\circ$ (of the curve at this point). Comparative study in the case of different heat-treatments of three plain carbon steels have resulted in the demonstration of the methods suitability in the case of normalizing, tempering, hardening and tempering, and furnace cooling.—M.L.

The work hardening of metals N. F. Mott (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 962-968) The theory of the work-hardening of metals is surveyed with an account of some hitherto unpublished ideas of Dr Hirsch. The formation of a slip line of length L in stage II hardening leads to secondary slip throughout a volume L^3 of the same order as about one-third of the primary slip. The secondary slip is responsible to most of the network of dislocations observed in cold-worked materials, and this network is responsible for about one half of the flow stress. The secondary slip also hardens the sources by forming glissile and non-glissile jogs; when the source is stressed hard enough these annihilate each other and the source is unlocked. The dislocations move until the jog density stops them. The forest density in Stage II work-hardening retains a value just big enough to stop the dislocations. The theory predicts the formation of vacancies in cold work but not of interstitials.

A simple test to predict the increase in permanent set of springs under repeated loading R. S. Loubser (*South African Mech. Eng.*, 1961, 10, Jan., 147-151).

Modern fatigue testing machines and their applications A. J. Yorgiadis (*Mechanical Properties of Metals - A Short Course*, Pennsylvania State Univ., 1958, 203-233).

Testing the tendency to crazing of cast iron used for steel ingot moulds A. Josefsson and B. Backström (*Jernkont. Ann.*, 1960, 154, (10), 739-756) A testing procedure consisting of alternate heating and cooling of cylindrical cast iron test pieces indicates that the test may be suitable for classifying cast irons with respect to their tendency towards crazing. (11 refs.)

Recent research on fatigue in metals P. G. Forrest (*Chartered Mech. Eng.*, 1961, 8, March, 148-157) A detailed review. A brief survey of future developments is included. (67 refs.)

Fatigue strength of metals T. J. Dolan (*Mechanical Properties of Metals - A Short Course*, Pennsylvania State Univ., 1958, 127-162).

Fatigue strength of mild steel after cathodic protection in sea water Y. Minami and H. Takada (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 30-32; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 180) Influence of electrode potential on fatigue strength of mild steel (as-rolled and shot-blasted specimens) after cathodic protection was investigated. Concludes that the electrode potential of the specimen during cathodic protection should be kept between -0.9 and -1.1 V, in order to hold fatigue strength in the air; a lower potential than the above would often lessen the fatigue strength, besides a remarkable increase in current density.—C.F.C.

Study of fatigue properties of ultra-high strength steel H. B. Nudelman and J. P. Sheehan (*PB 171056*, 1960, June, pp.65; *ARF 2172-6*; *WADD Tech. Rep.*, 60-120; from *US Res. Rep.*, 1961, 35, Jan. 13, 92) Relations of fatigue strength to melting and deoxidation practice were found.

Some quantitative aspects of fatigue of materials H. N. Cummings (*PB 171084*, 1960, July, pp.292; *WADD Tech. Rep.*, 60-42; from *US Res. Rep.*, 1961, 35, Jan. 13, 95) In this report are given not only fatigue properties of many structural materials but also the 'static' properties and such other supplementary information as was given in the references consulted. The data are in general from room temperature tests, but a few data are given on tests at higher temperatures. The data are presented in tables on curves, supplemented by brief discussions in the text.—C.F.C.

Detection of fatigue damage with Rayleigh waves P. J. Brosens, N. A. G. Hakimi, and G. R. Khabbaz (*PB 171099*, 1960, Aug., pp. 57; *ARL Tech. Rept.* 60-307; from *US Res. Rep.*, 1961, 35, Jan. 13, 94) Rayleigh waves show both damage prior to crack formation and cracks present later. With low-frequency waves (2mc) the prior damage was not detected.

Statistical analysis of fatigue data F. B. Stulen and H. N. Cummings (*Mechanical Properties of Metals - A Short Course*, Pennsylvania State Univ., 1958, 163-202) A very detailed presentation of the essentials.—C.V.

Propagation of cracks in steels under fatigue stresses A. Matting and H. Wolf (*Materialprüfung*, 1961, 3, Feb. 20, 51-62) The relationship between crack length and number of stress cycles is established by tests on specimens of various steels; the dependence of crack growth on nominal stress deduced, and the characteristics of crack propagation examined in relation to other material properties. (20 refs.)

Studies on the fatigue behaviour of strain gauges C. Rohrbach and N. Czajka (*Materialprüfung*, 1961, 3, April, 20, 125-136) The fatigue behaviour of strain gauges was studied with respect to dynamic or repeated static measurements. It was concluded that the sensitivity of the strain gauges is independent of the number of cycles, but that the zero deviation varies strongly in the case of great alternating stresses, though it varies slightly at small alternating stresses. At alternating strain amplitudes of close to 2%, fatigue

fracture in the gauge wire or in the terminal connexions was the only destruction cause of nearly all types tested.—M.L.

Accurate temperature control for creep/rupture testing installation Colvilles Ltd (*Metallurgia*, 1960, 62, Dec., 284).

Creep testing machine meets British emergency H. Robson (*Met. Prog.*, 1961, 79, Jan., 76-78) A creep testing machine built by D. Napier & Son Ltd, is illustrated and described. Creep tests of 2000 h duration have been carried out to compare the performance of the new machine with that of single point testers; six specimens taken from a common forging were tested simultaneously and there was less scatter in the creep measurements than is normally found in six separate test measurements. The machine has now completed 10000 h creep testing and it may be noted that continuous testing is possible since an individual specimen can be taken out and replaced without shutting down the machine and there is no detectable effect on adjacent tests.—C.V.

Some studies on fatigue of large steel specimens. 2. Propagation of fatigue crack on smooth surface specimens J. Hoshino (*Trans. Japan Soc. Mech. Engrs.*, 1960, 26, April, 567-577; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 175) Rotating bending fatigue tests on 0.2% C steel are reported using test-pieces 125 mm in dia. Shell patterns were observed on fractured surfaces when the stress was radically changed. These patterns take a definite shape, which can be drawn as a family of curves depending upon arc length of crack. The relation between propagating speed v_c (μ /cycle) of crack and stress (kg/mm^2) on the edge of the fractured surface is given by the following formula ($v_c = \sigma - \sigma_0/B$, where σ_0 is a critical value of $\sigma = 11.5 \text{ kg/mm}^2$, and is a constant depending upon the size of the specimen ($=17$ for 125 mm dia.))—C.F.C.

Some experiments on fatigue under multiple repeated stresses M. Kawamoto and M. Seki (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 15-19; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 174) Multiple repeated stress tests under two stress levels were carried out with nine specimens (Al alloy or mild steel), and the effect of cycle ratios of primary stress upon the fatigue damages at secondary stress was studied. Results were shown by several methods of representation, whose advantages and disadvantages are discussed. In particular, Levy's method is considered, but is pointed out to have a limit of application.—C.F.C.

Some experiments on the effect of rest periods during stressing in high temperature fatigue K. Endo (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 64-67; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 174) Fatigue life tested at high temp. is considerably prolonged when cyclic stresses are removed during the course of testing. The increase rate depends on the cyclic ratio up to the interruption, and this is explained by the relation between increasing hardness due to ageing and the irreversible damage accumulated by repeated stress. The accumulation of fatigue damage at elevated temp. can hardly be made clear from these simple tests which are made under rather a limited condition.—C.F.C.

Fatigue resistance: design considerations C. R. Smith (*Air. Eng.*, 1960, 32, May, 142-144).

Fatigue breakdowns in carbon steels M. Klesnil (*Met. Treatment*, 1960, 27, Dec., 503-510) Normalized carbon steel specimens (0.09, 0.4, and 0.8% C) were fatigued in reversed bending and the degree of hardening determined. Micro X-ray diffraction patterns were obtained and both optical and electron microscopic studies carried out. It is concluded that when persistent slip bands attain critical dimensions a microcrack is formed in them which propagates under high stress concentration conditions. These conclusions do not differ from those already reached by previous workers.—A.H.M.

Fatigue crack propagation (*Can. Mines, Research and Special Projects Report* 1960, 1961, 32) Characteristics of fatigue and impact fracture surfaces were studied using the optical microscope and scanning electron microscope.

The fracture surface of OFHC copper, tested in reverse plane bending was composed of a network of striations; these marked the advancement of the crack front. Second phase particles appear to restrict the propagation of the fatigue crack in CG 42-T6 (Alcan 24S-T6) Al-alloy. This restriction was shown by a wavy, distorted appearance of the striations on the fracture surface. Impact fracture surfaces of CG42-T6 tested at 195° and room temp. showed a network of dimples and craters. This structure is considered to be caused by a decohesion between second-phase particles and the Al solid solution phase as well as by the fracture of the hard particles.—C.V.

Effect of surface finish on fatigue resistance R. Mossoux and J. Collin (*Rev. M. Tijds.*, 1960, 6, (4), 209-210).

Fatigue and welding H. de Leiris (*Rev. M. Tijds.*, 1960, 6, (4), 179-182).

The fatigue strength of welded motor car disc wheels O. Iždinský (*Zdranie*, 1961, 10, (1), 3-5) [In Slovak].

Energy versus stress theories for combined stress—a fatigue experiment using a rotating disc W. N. Findley, P. N. Mathur, E. Szczepanski, and A. O. Temel (*Trans. ASME, J. Basic Eng.*, 1961, 83D, March, 10-14) It was found that fatigue cracks were produced in regions where the strain energy was essentially constant during the test; it was therefore evident that fluctuating strain energy could not be the prime cause of fatigue failure. It was inferred that fatigue failure must result from fluctuation of some component of stress or strain referred to particular planes of the material, e.g. a critical shear stress. It is considered that while strain-energy forms of expression may be useful as design formulae for combined stress, the experimental work described is not valid as a method of describing the mechanism of fatigue and if used may provide incorrect findings.—C.V.

On the contribution of residual stresses to the coxing of low carbon (S15C) and medium carbon steel (S40C) during repeated stresses in reversed bending S. Taira and Y. Murakami (*J. Japan Soc. Test. Mat.*, 1960, 9, May, 372-379; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug. 174) [No abstract].

On the residual stresses due to repeated stressing of annealed steels S. Taira and Y. Murakami (*Trans. Japan Soc. Mech. Eng.*, 1960, 26, April, 591-598; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 174) Tests are made to find whether repeated bending leaves residual compressive stress. It is shown to appear early and to reach a max. at $\sim 10^6$ cycles, afterwards fading out to vanish at or near fracture. Higher stresses are reached with higher C and with higher yield point.—C.F.C.

Crack propagation in thin metal [aluminium alloy] sheet under repeated loading H. W. Liu (*Trans. ASME J. Basic Eng.*, 1961, 83, March, 23-31).

Microplastic strain hysteresis energy as a criterion for fatigue fracture C. E. Felner and J. D. Morrow (*Trans. ASME, J. Basic Eng.*, 1961, 83D, March, 15-22) Hysteresis energy has been postulated as a criterion for fatigue failure; specifically, the plastic-strain energy portion of the hysteresis energy has been assumed to account for the damaging effects. SAE 4340 steel was used to study the cyclic and static stress-strains. The test procedure is described and the collected data are compared with the theoretical findings. Future investigations are suggested. It is pointed out that although static true stress-strain measurements may never replace experimental S-N curves, they may to some extent reduce the number of cyclic tests required.—C.V.

Photoelastic investigations on test bars for creep tests on brittle sintered materials W. Schatt and D. Kockott (*Materialprüfung*, 1961, 3, Feb. 20, 66-69).

Creep resistance and high temperature properties of metals G. V. Smith (*Mechanical Properties of Metals - A short course*, Pennsylvania State Univ., 1958, 111-125).

The practical realization of the HV and HR scales of hardness R. S. Marriner (*Quality Eng.*, 1961, 25, March-April, 52-58) A communication from the National Physical Laboratory. Experiments with precise indentation hard-

ness testing machines are described, in which the conditions of loading the indenter are varied, and the resulting variations in the hardness values obtained are discussed. Evidence of the necessity for precise control of the loading conditions in standardization work is given, together with the definition and accuracy of the HV scale of hardness provided by the National Physical Laboratory.—S.H.-S.

Hardenability bands for steels 6118-H to 8630-H (*Met. Prog.*, 1960, 78, Nov., 100B) A data sheet.

Hardness and its measurement for the metallurgist V. E. Lysaght (*Mechanical Properties of Metals - A short course*, Pennsylvania State Univ., 1958, 35-90).

Hardness testing of cast-iron machine-tool frames E. Fuchs (*Koh. Lapok-Öntode*, 1961, 12, Jan., 12-17) The Brinell hardness of cast-iron machine-tool frames can be determined within the standard limits of $\pm 7 \text{ kg/mm}^2$ with the manual hardness tester 'Poldi', if the dia. of the indentation has been measured with an accuracy of up to $\pm 0.02 \text{ mm}$, and a new, more detailed chart, shown in the present paper, has been used.—P.K.

Hardening and precipitation in an iron molybdenum and an iron-tungsten alloy G. Elsen and G. Wassermann (*Z. Metallk.*, 1961, 55, April, 263-269).

On the influence of pre-precipitation on the hardening of various alloys H. Borchers, M. Kainz and S. Pixner (*Z. Metallk.*, 1961, 52, April, 276-279) Results are discussed which show that under certain conditions, low temp. pre-precipitation may cause accelerated and increased, or retarded and decreased precipitation hardening. Age hardening is not affected. Pre-precipitation and age-hardening may prevent precipitation hardening. Explanations are offered and further tests are advocated.—R.P.

Investigations on the strain ageing of mild unalloyed steels, by means of strength and damping measurements W. Heller and M. Nacken (*Arch. Eisenh.*, 1960, 31, Dec., 723-730) The process of strain ageing was followed on specimens of basic Bessemer steel, special blown steel and electric steel with a dissolved C content of 0.019% at various temp. by means of tensile tests and damping and coercive power measurements. The results are discussed in relation to the effects of carbide formation on the mechanism of strain ageing. (17 refs.)

Current views on brittle fractures A. V. Núñez (*Cien. Tecn. Solda.*, 1961, 11, Jan.-Feb., 1-10) [In Spanish].

Theory of brittle crack initiation and propagation - a theoretical analysis of E880 test Y. Akita and K. Ikeda (*Weld J.*, 1961, 40, March, 138s-144s) Information is presented from the viewpoint of dynamics on the effects of impact energy, temp. yield stress, and plastic surface energy on brittle crack initiation and propagation.—S.H.-S.

ERRATUM

JISI, 1961, 198, June, p.214 line 19.
For 'PB 145861' read 'PB 147861'.

Joint investigation on brittle fracture in service Instituto Internacional de la Soldadura (*Cien. Tecn. Solda.*, 1960, 10, Oct., 1 (17), 1-6) An account of the procedure to be adopted by members of the IIS Comision IX in studying and collecting data on brittle fracture in service.

Catastrophic fracture caused by ductile-to-brittle transition W. N. Platte (*Weld J.*, 1961, 40, March, 135s-137s) Results of original studies in Mo as a means of examining the relationship between transition temp., residual welding stresses, and catastrophic rupture are presented and discussed. It is shown that post-weld stress-relief treatments applied before the welds cool below the ductile-to-brittle transition temp. prevent the catastrophic cracking found in the weld crater area.

Brittle failure of strong tough steel C. E. Mavrocordatos (*Met. Prog.*, 1961, 79, Jan., 130-132) The essential requirements of a

simple test for brittle fracture are outlined and attention is drawn to the similarity between temper brittleness of certain alloy steels and the brittle fracture of 'tough' mild steel; equally, there are puzzling differences. A tentative theory to explain this is presented by the author (*J. South African Inst. Min. Met.*, 1960, July, 709). A general guide to the characteristics of a satisfactory mild steel is given.—C.V.

Blue-brittleness A. Josefsson (*Jernkont. Ann.*, 1960, 144, (11), 834-846).

Blue-brittle Armco iron A. W. Sleeswyk (*Acta Met.*, 1960, 8, Feb., 130-132) A letter. The character of the irregular stress-strain curves obtained with Armco iron showing the characteristics of blue-brittleness, and the connection between diffusion of interstitials and this type of deformation, are examined in detail. The results indicate that a critical strain rate exists which represents the transition between unstable plastic deformation and stable deformation. This critical rate was determined, and the results are discussed.

The effect of stratification in the structure of structural steels on anisotropy in the mechanical properties and on the cold-shortness threshold I. V. Navrotskii, and L. V. Krivenko (*Stal*, 1961, (4), 350-354) Steels St3, 10KhSND and 19G (low-alloy) were examined and no relationships were found between structural non-uniformity and cold-shortness or mechanical anisotropy, which was always present after rolling but was increased by stratification of the ferrite.

The metallurgical aspects of hydrogen embrittlement in metal finishing H. J. Read (*Tech. Proc. Amer. Electroplaters Soc.*, 1960, 110-115; discussion 241) Stress-strain relationships in flow and fracture, the way in which occluded hydrogen can affect the normal behaviour and the problems of removing or avoiding hydrogen embrittlement are reviewed.—A.D.H.

Measurements pertaining to hydrogen embrittlement C. A. Snavely (*Tech. Proc. Amer. Electroplaters Soc.*, 1960, 138-142) Methods of determination in steel, methods of charging specimens, mechanical testing and special methods are reviewed. (24 refs.)

A new look at the hydrogen embrittlement of cadmium coated high strength steels N. M. Geyer, G. W. Lawless, and B. Cohen (*Tech. Proc. Amer. Electroplaters Soc.*, 1960, 143-151; 244-246) A sustained load applied to a notched tensile test-piece loaded at 75% of the ultimate notched tensile strength for 200 h formed the basis of a test to detect H_2 embrittlement. The embrittling action of commercial Cd plating baths was investigated.

The effect of heat-treatment on the toughness of alloy tool steels. 2. On the abrasion resisting and non-deformable tool steel SGT and YGT S. Koshiba and A. Inata (*Hitachi Hyoron*, 1960, 42, May, 587-590; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 272) [No abstract].—C.F.C.

Surface contact in theory and practice F. T. Barwell (*Inst. Mech. Eng.*, 1961, April, 12, 3-26).

Special methods of nondestructive testing H. J. Rodewald and C. Studer (*Metall.*, 1961, 15, May, 410-414).

Visual strain gauge, does work of three F. Zandman (*Prod. Eng.*, 1960, 31, Oct. 24, 42-44) A photoelastic strain gauge is described which measures, without a polariscope, the magnitude and direction of the separate principal strains at the point at which the gauge is attached. It is called a 'rosette' since the results are shown by a rosette pattern of three resistance strain gauges. It consists of three resistance strain gauges. The calculation of principal strains is discussed mathematically and a diagram illustrating these is given. The Golubovic device, requiring auxiliary instrumentation, is also discussed.—C.V.

Nondestructive testing is key to future of welding quality control G. J. Gibson (*Weld J.*, 1961, 40, March, 225-228) A general survey and applications of probing media used in non-destructive weld tests are presented. Motion of matter, transmission of energy, magnetic particle inspection, and the inspection of welded joints are discussed.—S.H.-S.

Non-destructive testing of tubes M. Zdunkiewicz (*Hutnik*, 1961, 28, (2), 62-64) A discussion of an American report of the API Committee on standardization of tubular goods presented at Denver, USA.

What about flaws in your machines? [magnetic powder testing] F. Housman (*Metalw. Prod.*, 1961, 104, April 5, 51-52).

Processing and properties of magnetic materials R. H. Trapp ('Flat rolled products. II. Semi-finished and finished', Interscience Publishers, 1960, 6, 99-114) The seven factors that influence magnetic properties are listed, degree of purity, texture, order-disorder, magnetostriiction, grain growth, strain and magnetic or field annealing; none of these are free and independent of each other for if a material is heat-treated grain growth and purification can occur at the same time. Crystal orientation and the effects of cold rolling are discussed and crystal orientation in NiFe and SiFe is examined. When truly isotropic magnetic properties are required, then preferred crystal orientations must be avoided and the material must be processed in such a way as to prevent texture development.

Processing and properties of magnetic materials P. H. Estes ('Flat rolled products. II. Semi-finished and finished', Interscience Publishers, 1960, 6, 115-130) Discussing punchability, the effect of the material on die life is examined; cold-reduced grades have an index of 200 and 150 for motor or electrical grade as-rolled, 90 after normalizing and 40 after box anneal. It is also stressed that punching strains introduce a degree of degradation in magnetic properties which must be relieved in most cases by annealing but examples are also given showing values of core loss and excitation resulting from annealing conditions on 0-025 in common iron. Distortion and sticking is briefly reviewed. An informative diagram is presented showing the magnetic performance of new materials. Cube texture Si-iron and Si-steel usage are briefly reviewed.—C.V.

Study on the OP magnet (4th rep.) Solid phase reaction in the formation of OP magnet H. Nakamura and N. Kawai (*J. Japan Soc. Powder Met.*, 1959, 6, Oct., 181-184) The magnet is prepared from the mixed metal nitrate by ignition, compacting and sintering *in vacuo*. The constituents are identified and the reaction on firing is inferred. A diffusion mechanism developed and the activation energy estimated.

Nuclear and paramagnetic resonance G. K. Fraenkel and B. Segal (*Ann. Rev. Phys. Chem.*, 1959, 435-456).

Some observations on transformer steel J. Teindl and B. Otta (*Sborník, Ostrava*, 1960, 6, (3-4), 297-301) [In Czech] The suggestion that prolonged storage in the open may affect the electromagnetic and mechanical properties of transformer sheet significantly was examined. It was found that storage from May to August in the open had no significant effects; the permeability differences in sheet depend primarily on those of the bar stock from which they were rolled.—P.F.

Ultrasonic testing J. F. Hinsley (*Edgar Allen News*, 1961, 40, April, 76-77) A brief review of the work of the joint Summer Conference on non-destructive testing, with a list of the eight lectures delivered.—S.H.-S.

How the Russians are using ultrasonics in metallurgy A. B. Tesman (*Met. Prog.*, 1961, 79, Jan., 79-83) Ultrasonics are being used to degas molten metals, speed diffusion processes such as carburization, accelerate ageing of Al-alloys and improving weld quality.—C.V.

The attenuation of ultrasonic waves in austenitic chromium-nickel steels P. Midecke (*Materialprüfung*, 1961, 3, Jan., 20, 1-4) The small depth of penetration of ultrasonic waves in these steels is due to the precipitate-rich structure; due to increasing extinction the depth of penetration decreases with rising C content, and varies with the treatment of the steel, i.e. whether forged, rolled or as-cast. The depth of penetration is investigated theoretically from the coefficient of extinction.

Methods and scope of ultrasonic testing K. Vařica (*Hutnik*, 1961, 11, (3), 123-128) [In Czech].

Radiographs to set navy casting standards R. J. Ely (*Foundry*, 1961, 89, April, 167-168) Radiographic standards for steel castings with sections from 0.13 to 0.75 in now being prepared for the Bureau of Naval Weapons by the Naval Ordnance Laboratory, Silver Spring, Maryland, to meet advances in casting techniques and light steel castings for aircraft and missiles, and their uses and applications, are briefly discussed.—S.H.-S.

Optimum fault detection in radiographic weld examination G. J. Janssen (*Materialprüfung*, 1961, 3, Feb. 20, 63-66) [In English].

Determination of the residual austenite content in hardened steels by means of X-ray diffraction analysis E. G. Fuchs (*Acta Techn. Hung.*, 1961, 32, (3-4), 389-414) A survey of papers on X-ray diffraction analysis for austenite determination has enabled the development of a method suitable for determination of the residual austenite content in hardened steels. A relationship has been derived which is essentially independent of the steel composition and use has been made of the fact that the integrated reflection of austenite and martensite are proportional to the amount of these phases. Evaluation curves have been plotted which enable determination of the austenite content within 1-2 minutes, with satisfactory accuracy. (24 refs.)—M.L.

Radiation effects on metals J. C. Wilson ('Mechanical Properties of Metals - A short course', Pennsylvania State Univ., 1958, 263-275) The unusual behaviour of irradiated metals is discussed, this being probably due to the lattice defects that have been produced. However, it is possible that this treatment may have speeded up metallurgical reactions; some experiments suggest this and the necessity for a careful study of irradiation temp. is indicated. The fact that high purity Fe (even if alloyed with C) is immensely superior to steels in resistance to radiation-induced shifts in transition temp. suggests that radiation resistant steels should be possible. The various aspects of this problem are examined.—C.V.

Tungsten-element furnace with zirconia lining promising for heating in the range of 4000°F C-M Inc. (*Indust. Heat.*, 1960, 27, Dec., 2580-2584).

High temperature chemistry J. L. Margrave (*Ann. Rev. Phys. Chem.*, 1959, 457-486).

Chemical composition and thermal expansion of Fe-Ni alloys used for so-called Dumet wires E. G. Fuchs (*Acta. Techn.*, 1960, 31, 3/4, 425-435).

Reactions of metal surfaces at high temperatures F. T. Barcroft and J. R. Hayden (*Nature*, 1961, 189, Jan. 14, 133-134) A letter. High temp. reactions of extreme-pressure lubricants with metal surfaces are investigated by simulated pulse heating with X-ray examination of the products. The core of a stainless steel wire with various S compounds is illustrated.

Stress-rupture tests at 1350°F on type 304 stainless steel W. D. Jenkins, W. A. Willard, and W. J. Youden (*Mat. Res. Stand. Bull. ASTM*, 1961, 1, Feb., 104-108) A stress-rupture test programme statistically designed to obtain maximum amount of data from a limited number of tests is reported. Specimens tested at a stress of 13500 psi had an average rupture life of 100 h. Results were analysed. Standard deviation was 20 h. The effect of stress on the properties of material is reported.

Vapour pressure of iron at 1600°C E. T. Turkdogan and L. E. Leake (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 1136-1137).

Study on type 321 stainless steel intended for high temperature service M. Nishihara, H. Hirano, S. Yamamoto, and K. Yoshida (*Proc. 3rd Japan Congr. Test. Mat.*, 1960, 72-76; from *Japan Sci. Rev. Mech. Elect. Engr.*, 1960, 7, Aug., 273) Vacuum melted and in-air melted specimens of type 321 stainless steel (Ni-Cr-Mn steel containing Ti) are tested; effects of heat-treatment on creep rupture strength and the behaviour of TiC in austenite, before and after creep rupture tests, are discussed.

Self-diffusion in alpha iron R. J. Borg and C. E. Birchenall (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 980-984) The self-diffusion coefficients for α -iron have been determined between 980° and 1167°K using ^{56}Fe as the

tracer. With decreasing temp. the diffusivity was found to decrease more rapidly than predicted by the Arrhenius equation in the region of the Curie temp. The diffusion coefficients obtained well above the temp. of the magnetic transformation are more precise and differ substantially from all previously reported values. In the temp. region beginning at least 50° above T_c , the diffusion coefficient is given by $D = 118 (\pm 2) \exp (-67240/RT) \text{ cm}^2 \text{ sec}^{-1}$.

Determination of diffusion coefficients in iron-chromium alloys T. Heumann and H. Böhmer (*Arch. Eisenh.*, 1960, 31, Dec., 749-754) The diffusion coefficients in Fe-Cr alloys with 0-22at-% Cr were determined. The coefficients in α -solid solutions fall with additions of up to 10at-% Cr by about 30%, remaining unaltered with further additions. The coefficients in α -solid solutions are about two powers of 10 lower than those of the α -solid solutions. The diffusion of the Cr atoms is slightly increased in the presence of Al (14 refs.).

Diffusion in the iron-chromium system H. W. Paxton and T. Kunitake (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 1003-1009) The self-diffusion coefficient of Cr in various alloys in the iron-chromium system has been measured. A variation in D_0 from 10^{-4} for pure Cr to a maximum of 10^2 near 60%Cr appears with a range of activation energy from about 50 to 80 Kcal per mol. The general pattern of behaviour observed is not consistent with present theories of diffusion by a vacancy mechanism. Suggestions are made for further clarifying experiments.—S.H.-S.

The self-diffusion of iron through grains and at grain boundaries. Part II C. Leymonie (*Mémoires*, 1960, Feb., 45-65) Using radioisotopes it was established that grain boundary self-diffusion is pronounced at temp. below 850°C and depends upon the orientation of the crystal boundary. Values were determined for the self-diffusion coefficient of α -iron and for energies of activation in α - and γ -iron. Grain boundary segregation of impurities assists self-diffusion. (51 refs.)—A.D.H.

The diffusivity of hydrogen in alpha iron E. W. Johnson and M. L. Hill (*Trans. Met. Soc. AIME*, 1960, 218, Dec. 1104-1112) The diffusivity D was determined at 25° to 780°C from hydrogen evolution rates. Anomalous evolution from air-melted iron was attributed to residual hydrogen, which is interpreted as a hydrogen compound that decomposes at a strongly temperature-dependent rate above 500°C. Above 200°C, $D = 0.014 \text{ cm}^2 \text{ sec}^{-1} \exp (-3200 \text{ cal per g atom/RT})$. Below 200°C the diffusivity is anomalously low and represented by $D = 0.12 \text{ cm}^2 \text{ sec}^{-1} \exp (-7820 \text{ cal per g atom/RT})$. It is postulated that at low temperatures the hydrogen in the metal is 'trapped' with an energy 4.8 Kcal per g atom below that of the interstitial hydrogen.—S.H.-S.

Diffusion of xenon through aluminium and stainless steel A. W. Castelman, F. E. Hoffmann, and A. M. Eshaya (*BNL-624 (T-190)*, 1960, July, pp.9; from *US Res. Rept.*, 1961, 35, Jan.13, 126) [No abstract]

The behaviour of hydrogen in iron and steel M. L. Hill (*Tech. Proc. Amer. Electroplaters' Soc.*, 1960, 124-134; discussion 242-243).

The effects of hydrogen in welded, cast and cold-worked steel P. Bastien (*Zvár. Sborník*, 1960, 9, (3), 345-366).

METALLOGRAPHY

Heterogeneous equilibria and phase diagrams R. F. Porter (*Ann. Rev. Phys. Chem.*, 1959, 219-246).

Methods of constructing structural diagrams in ternary systems I. Vladescu (*Bergakademie*, 1960, 12, Dec., 705-709).

Causes and occurrence of the anomalous structure in steels H.-J. Wiester, R. Pusch, and M. Hoffmann (*Arch. Eisenh.*, 1960, 31, Dec., 731-747) The influence of various impurities and alloying elements on the formation of steel structure was determined on pure hyper-eutectoid Fe-C alloys. Additions of Mn, Si, Al (as an alloying element) and As counteract the structural anomaly in pure Fe-C alloys, while O_2 , P and Cu promote it. S and N_2 have no effect. The mechanism of the influence of

additions on this structural anomaly is discussed. (67 refs.)

Metallurgical preparation of sharp edges P. G. McDougall and N. F. Kennon (*J. Australian Inst. Met.*, 1960, 5, Nov., 200).

A metallographic study of precipitation of copper from alpha iron E. Hornbogen and R. C. Glenn (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 1064-1070) Copper precipitates from α -iron or fcc ϵ -phase without formation of intermediate compounds. In the first stage of the precipitation, spherical particles with diameters $<100\text{\AA}$ are formed at a high rate. During the second stage, the particles grow at a rate given by Zener's equation for growth of a spherical precipitate. In the third stage, growth is slower. Rod-shaped particles form after long ageing times at 700°C . Maximum strengthening was observed at the beginning of the second step of precipitation. During plastic deformation of the aggregate, particles appear to deform initially by twinning.

Process of dissolving carbides in austenitized W-V-Cr steels Z. Bojarski (*Prac. Inst. Hutniczych*, 1960, 12, (6), 263-272) Up to 1200°C there is a little change in the lattice of the carbide M_6C , its outer layers poorer in W, being dissolved by the matrix. Above 1200°C their amount decreases, their lattice expands, and there is an overall growth of undissolved carbides which become polygonal. The crystallites coagulate and layers more rich in W are deposited on them. These large crystals of carbide are difficult to dissolve when the steel is being thus eliminated from the process of saturating the matrix with alloy elements they cause brittleness and premature fractures of the tools.

The dissolving of oxides in carbon steel melts under vacuum L. Tiberg (*Jernkont. Ann.*, 1960, 144, (10), 771-793) [In English] The rate of solution of oxides in a steel melt containing 0.8% C under vacuum was investigated, the mechanism discussed and equations describing the rates of solution derived.

Investigation of specially shaped titanium- and sulphur-containing inclusions in pig iron melts with high carbon contents (*Arch. Eisenh.*, 1960, 31, Dec., 755; correction to above article, cf *ibid*, 1960, 31, 419-422) Frau H. Kolbe's name should be inserted as a co-author of the above report.

Separation and determination of oxide inclusions in plain carbon steel with a methanolic bromine solution. III. Comparison of the behaviours of various component inclusions of steel in methanolic bromine and iodine solutions. IV. Comparison of the behaviours of some complex compounds of oxides in methanolic bromine and iodine solutions. V. Behaviours of inclusions of iron and steel in methanolic bromine and iodine solutions Y. Okura (*Nippon Kinzoku*, 1960, 24, (5), 289-293; 293-295; 296-300) [In Japanese] III. Most inclusion materials behave similarly in both solns., MnO is less stable in Br_2 than in I_2 soln. The iodine method is more subject to interference by FeS and nitrides of Fe and Mn. IV. Fe_3P in ferrophosphorus behaves similarly in both solns. Fe carbide is dissolved and causes no interference. Tephroite (a silicate ore) and OH slag gave low values in Br_2 soln. at 60°C . V. For separation of oxide inclusions in plain C steel containing $<0.5\%$ C, 10% methanolic Br_2 soln. is more suitable, rapid, specific and cheap.

Microstructures and notes on carbon steels made to BS 3100: grades A and B J. Turton and B. H. C. Waters (*Brit. Found.*, 1960, 53, Dec., 524-530).

Microstructures and notes on carbon-manganese steels made to BS 3100: 1957: 1456 grades A and B J. Turton and B. H. C. Waters (*Brit. Found.*, 1960, 54, Jan., 18-23).

Abnormal grain growth and intergranular segregation in iron. Part II. P. Coulomb (*Métall.*, 1960, Feb., 66-82) Radioisotope techniques were used to study the intergranular segregation of S in Fe-Si and Fe-Si-Mn alloys during annealing. The influence of such segregation in modifying the kinetics of the changes taking place and in changing the structure and the texture is used to explain abnormal grain growth.—A.D.H.

The effect of dilute transition element additions on the recrystallization of iron E. P.

Abrahamson and B. S. Blakeney jun. (*Trans. Met. Soc. AIME*, 1960, 218, Dec., 1101-1104).

The effect of the cooling rate on dendritic segregation of the liquid binary alloys C. Adamski (*Prz. Odlew*, 1961, 11, (3), 65-71).

Ferritic phase in austenitic acid-resisting steels H. Servicki, H. Brudzewski, and E. Karch (*Hutnik*, 1961, 28, (2), 51-55) The amount of the ferritic phase does not depend solely on the chemical composition; heat-treatment is another important factor. Ferritic phase does not however interfere with rolling so far as strips and bars are concerned. As for tube making, Polish experience was that if the ferritic phase exceeded 20% the amount of rejects made the production uneconomical, the Soviet standard allowing only for 12% of ferritic phase in steels for tube-making has therefore been adopted. A typical analysis ensuring this condition was: C: max. 0.10%, Mn: max. 2.0%, Si: max. 0.8%, Cr: 17-18%, Ni: 10-11%, and Ti: max. 0.8%.

Zigzag configurations of twins in α -iron A. W. Sleeswyk and J. N. Helle (*Acta Met.*, 1961, 9, Apr., 344-351) It is suggested that the occurrence of zigzag configurations of twin bands introduced by deformation at low temp. of high-purity iron does not seem to have been mentioned in the literature before. A description is given of zigzag configurations of twin bands in α -iron, obtained after a few per cent strain in tension or compression at the temp. of liquid O_2 . It is shown that these configurations can be adequately explained by considerations on the geometrical and mechanical compatibility of the twelve possible {211} {111} twin systems. The mechanical criteria for the formation of the zigzags are found to be different in tension and compression.—S.H.S.

CORROSION

Possible economies if the new theory of the corrosion of iron is correct R. Brocard (*Usine Nouv.*, 1961, 17, March 30, 120) [In French] This short article describes the researches of two American scientists who now consider the hydrogen-ion or proton to be the real agent of corrosion. Experiments which led to this conclusion are outlined.

Calculation of pipes buried under pressure R. Prevost (*Centre Belge d'Etude et de Documentation des Eaux*, 1958, (94), 292-294).

The renovation of old steel pipeline systems damaged by the action of soil or stray currents G. Poirier (*Centre Belge d'Etude et de Documentation des Eaux*, 1958, (94), 295-298) A method is described by which the parts of the system in poor condition can be located for replacement.

Cast iron and corrosion in the gas industry H. H. Collins (*Chem. Ind.*, 1961, Jan. 14, 32-38).

Corrosion and the gas consumer F. C. Moody and C. H. Purkis (*Chem. Ind.*, 1961, Feb. 4, 119-137).

Internal protection of gas mains D. Tinbergen (*Centre Belge d'Etude et de Documentation des Eaux*, 1958, (94), Oct., 278-280).

Intergranular corrosion of austenitic steels, containing 24%Cr and 19%Ni V. Cihal and P. Grobner (*Met. Treatment*, 1961, 28, Jan., 5-12, 13) The authors consider the thermochemical stability of chromium carbide and then deal at length with the kinetics of its precipitation. Electron micrographs are then presented illustrating the various types of intergranular corrosion and the authors then conclude that the precipitation of chromium carbide on the grain boundaries leads to decrease in the chromium content in the surface layer of the grain, below the passivation limit, thereby creating the necessary conditions for intergranular corrosion.—A.H.M.

Failure of steam-water heat exchangers B. F. Brown (*Metals, Eng. Quart.*, 1961, 1, Feb., 68-74).

Corrosion fatigue (*Can. Mines, Research and Special Projects Report*, 1960, 1961, 29).

Corrosion-fatigue strength of pump rods R. M. Raskin and R. A. Bagramov (*Ustaloist' Metall.*, Moscow, 1960, 138-147) Factors examined include methods of increasing corrosion-fatigue strength and the effect of asymmetrical loading. Pump rods are used in deep oil wells and serve as a kinematic link

between the pumping engine on the bottom and the deep plunger pump let into the well at a depth of 2500 m or more. They are made of steel, of circular cross-section 16-25 mm in dia. and 8 m long.—A.I.P.

Fretting corrosion (*Can. Mines, Research and Special Projects Report* for 1960, 1961, 28-29) Using a modified plate and oscillating sphere machine, the tangential surface elasticity between two contacting surfaces has been measured. Quite small additions of surface active components, notably oleic acid, result in a marked decrease in the apparent limit of elasticity between the contact surfaces of the SAE 6150 steel. Using oleic acid as an anti-fretting additive was disappointing but various other additives are being examined. Microscopical techniques have so far failed to reveal any direct similarity between surface slip markings during fretting and fatigue; this may be due to technical inadequacy and the work is being continued. Some preliminary observations suggest that the surface profile across the fretted area may provide a parameter by which to relate fretting to the conditions existing during the fretting process. Show profiles have shown relatively deep pits formed by fretting and the relation between number and depth and the mechanical factors of load, amplitude, and frequency are being studied.

Observations on the behaviour of plain carbon steels brought into contact with bismuth P. Spinedi and G. Signorelli (*Met. Ital.*, 1960, 52, Dec., 941-944).

The corrosion of high alloy steels by nitric acid. II J. Binger (*Werks. Korros.*, 1961, 12, March, 141-148) Results of corrosion tests in up to 67% HNO_3 , and up to atmospheric boiling points, were plotted as isocorrosion diagrams which can be used to predict the corrosion resistance of the steels under given conditions. A steel containing 0.1% C, 30% Cr, and 20% Ni gave the best results, and showed no intercrystalline corrosion, even after heat-treatment at 680°C , when exposed to boiling 50 and 67% HNO_3 .

Investigation of the enrichment in impurities during the oxidation of steel, using radioactive tracers C. de Beaulieu, M. Cagnet, and J. Moreau (*Rev. Mt. Mém. Sci.*, 1960, 57, Nov., 863-875) The accumulation at the Fe-oxide interface of Cu, Co, Cr, W, As, P, and S was confirmed by the use of radioisotopes. Examination of an Fe-S alloy with 0.021% S showed that oxidation in H_2 - H_2O atmospheres followed a linear succeeded by a parabolic law (14 refs).

Deposits and corrosion from combustion gases N. Y. Kirby (*Austral. Eng.*, 1960, 52, Dec., 60-62).

Formation of iron deposits in recirculation steam boilers N. N. Man'kina, M. M. Przhivalovskii, Yu. M. Bulavitskii, and I. I. Petrova (*Brit. Power Eng.*, 1961, 2, March, 60-63; from *Teplotenergetika*, 1959, 6, (2), 79-83).

Acid deposition in oil-fired boilers: Comparative trials of additives and testing techniques P. A. Alexander, R. S. Fielder, P. J. Jackson, E. Raask, and T. B. Williams (*J. Inst. Fuel.*, 1961, 34, Feb., 53-72) The trials at Bromborough and Ince power stations are reported; both burnt residual fuel oil containing 2.9-4.6% S and comparison was also made on various techniques for assessing the acid-depositing tendency of flue-gas; this included a survey of the concentration of SO_3 in this gas at different locations of two types of boiler. It was found that MgCO_3 , Zn-dust and a proprietary preparation greatly reduced the concentration of H_2SO_4 at the air-heater inlet and outlet; MgCO_3 was the cheapest, the proprietary preparation caused the greatest fouling of the air heater and Zn fouled the burner ports, which interfered with combustion. Dual firing (coal:oil, ratio 1:10), and pulverized fuel-ash injection caused severe fouling of the air heater by ash and H_2SO_4 and there was no significant difference between the amount of SO_3 produced by pressure atomizing burners at Ince and the steam-atomizing burners at Bromborough. The conversion of S in the fuel to SO_3 was dependent on the O_2 -content of the flue gas.—C.V.

Corrosion of metals in tropical environments. Part 5. Stainless steels B. W. Forgeson, C. R.

Southwell, and A. L. Alexander (*PB 161749*, 1960, Sept., pp.24; *NRL Rep.* 5517; from *US Res. Rep.*, 1961, 35, Jan. 13, 96).

Corrosion and incrustation from use of blast-furnace gas in gas turbines (*Corros. Techn.*, 1960, 8, Jan., 13-14).

Some aspects of the corrosion of steel in concrete D. A. Lewis (*Corros. Prev.*, 1961, 8, April, 42).

Corrosion problems and their treatment. VIII [Shipping] (*Corros. Prev.*, 1961, 8, April, *Corros. Engr.*, 1-V).

Practical corrosion problems in the Royal Canadian Navy T. H. Rogers (*Corros. Prev.*, 1961, 8, April, 44).

Corrosion and protection of aircraft H. G. Cole (*Corros. Prev.*, 1961, 8, April, 45).

Rapid pitting corrosion on gas scrubber J. T. Firestone (*Corrosion*, 1960, 16, Dec., 9-10).

Corrosion in oil refinery equipment H. G. Geerlings and J. C. Jongebreur (*Corros. Prev.*, 1961, 8, April, 43).

High temperature corrosion in refinery and petrochemical service E. N. Skinner, J. F. Mason, and J. J. Moran (*Corrosion*, 1960, 16, Dec., 593t-600t) Corrosion phenomena in refining service at elevated temp. are discussed, with particular reference to oxidation, sulphurization, and carburization. Basic considerations for the selection of suitable alloys for high-temp. corrosive environments are outlined.—G.F.

Storage tank life: extension through design and treatment C. K. Aldrich (*Corros. Techn.*, 1961, 8, Jan., 17-18).

Aqueous corrosion in atomic energy industry W. T. Edwards (*Corros. Prev.*, 1961, 8, April, 46).

Corrosion of nuclear power plant tube materials by boiler sludge E. Howells, T. A. McNary, and D. E. White (*Corrosion*, 1960, 16, Nov., 571t-576t) The authors have investigated the corrosion effects of a sludge accumulation on various pressurized water nuclear power plant tubing alloys. The alloys in descending order of corrosion resistance, were Inconel, type 347 stainless steel, Croloy 16-1, Monel, and carbon steel.—G.F.

Stress-corrosion cracking of high-strength oil country tubular goods R. S. Ladley (*Corrosion*, 1960, 16, Nov., 539t-542t).

Corrosion mechanisms in ammonia synthesis equipment V. Cihal (*Corros. Prev.*, 1961, 8, April, 43).

Some unusual corrosion problems in the chemical process industry M. G. Fontana (*Corros. Prev.*, 1961, 8, April, 43).

Aspects of stress-corrosion cracking in austenitic stainless steels D. van Rooyen (*Corros. Prev.*, 1961, 8, April, 47-48) The addition of small amounts of N or larger amounts of Mo reduces the resistance of austenitic stainless steels to transgranular stress-corrosion cracking. Increase in the C or Ni content, possibly also Sn, makes the alloys more resistant to cracking. Potential measurements show that strain induced anodic depolarization cannot alone account for cracking and preference is given to an electrochemical mechanism where the reaction takes place at sites of structural and composition change; these may be formed under the influence of stress which sets up paths of easy localized corrosion.—C.V.

Stress-corrosion cracking of single crystals of some austenitic stainless steels R. E. Reed and H. W. Paxton (*Corros. Prev.*, 1961, 8, April, 47) Fe-20Cr-20Ni, Fe-20Cr-12Ni and commercial 304 stainless steel crystals were loaded in tension in boiling 42% MgCl₂. The 304 commercial stainless steel cracked or fractured in 4-17 h, the Fe-20Cr-12Ni in 16-62 h and the Fe-20Cr-20Ni in 70-170 h. In all three, the crack nucleated from elongated pits formed when portions of the slip lines were attacked by the solution. The crack planes of each of the specimens are discussed. From the observations it is considered that the process proceeds in two steps; a slow electrochemical crack initiation and a re-initiation step which is followed by a rapid mechanical fracture step.—C.V.

Stress corrosion cracking of carbon steels in concentrated sodium nitrate solutions R. L. McGlasson, W. D. Greathouse, and C. M. Hudgins (*Corrosion*, 1960, 16, Nov., 557t-562t)

The authors have studied the operating and metallurgical variables governing failure of steel in nitrate solutions. The results are enumerated and are considered applicable to a variety of low-alloy AISI steels.—G.F.

Corrosion problems in the use of dense salt solutions as packer fluids C. M. Hudgins, J. E. Landers, and W. D. Greathouse (*Corrosion*, 1960, 16, Nov., 535t-538t).

Corrosion-erosion of sensitized AISI Type 304 stainless steel in a thorium dioxide-uranium trioxide slurry D. C. Vreeland (*Corrosion*, 1961, 17, Jan., 21t-24t) Corrosion test loops have been used to evaluate the corrosion-erosion of type 304 stainless steel in ThO₂-UO₃ slurries. The difference in behaviour between as-received, sensitized, and sensitized and pickled material is described.—G.F.

Cracking of low carbon steel by ferric chloride solution M. B. Strauss and M. C. Bloom (*Corrosion*, 1960, 16, Nov., 553t-556t) The authors describe experiments which show that mild steel can undergo stress-corrosion cracking in FeCl₃ solutions at 316°C. Similar results can be obtained with chloride-bearing slurries of the ferric oxides and hydrated oxides. The significance of these results in boiler operation is discussed.—G.F.

Design considerations for the reduction of corrosion of works structures and equipment A. J. P. Tucker (*South African Mech. Eng.*, 1961, 10, Jan., 156-164).

Alternating current corrosion F. O. Waters (*Corros. Prev.*, 1961, 8, April, 52-53).

Corrosion of steel by microbiological oxidation of reduced inorganic sulphur compounds J. Horvath (*Corros. Prev.*, 1961, 8, April, 52) Solutions were inoculated with a mixed culture of thiobacilli which lowered the pH to 3.0 due to formation of free H₂SO₄. Anodic and cathodic polarization curves were measured at different stages. Weight loss and changes in slope of the polarization curves showed that oxidation of reduced inorganic S-compounds greatly increased corrosion rate. The results were compared with those found in the field.—C.V.

Corrosion of mild steel by sulphate-reducing bacteria G. H. Booth and F. Wormwell (*Corros. Prev.*, 1961, 8, April, 53) Different strains of SO₄-reducing bacteria have been examined and a wide variation in corrosion rate activity has been noted. There is a striking linear correlation between corrosion rate and the H absorption coefficient, the hydrogenase activity for S reduction in the case of fresh water organisms. This was found despite the fact that there was no control of growth rate.—C.V.

Anaerobic corrosion of tinned steel in citric acid S. C. Britton and K. Bright (*Corros. Prev.*, 1961, 8, April, 42).

Oxidation of iron-carbon alloys H.-J. Engell and K. Bohnenkamp (*Corros. Prev.*, 1961, 8, April, 51) A discussion of the findings of various workers.—C.V.

Oxidation of iron-nickel alloys. IV. Further electron diffraction studies at elevated temperatures R. T. Foley (*J. Electrochem. Soc.*, 1961, 108, March, 216-221) The oxide films formed on Fe-Ni alloys containing 30, 41, 78 (3.8% Mo) and 80 Ni have been examined at their formation temp. up to 1000° with electron diffraction and the influence of the alloy substrate greatly influences the structure of the films first formed. The influence of Mo at 900° is discussed and it is concluded that MoO₃ first forms but is seldom seen since it remains at the metal-oxide interface as the film grows. When H₂O vapour is present in the oxidizing gas a spinel of unit cell dimension $a_0 = 8.50-8.60$ is observed on the 30 and 41% alloys. This lattice is expanded in comparison with the spinel NiFe₂O₄ ($a_0 = 8.33$) observed on these alloys in previous experimentation and agrees with MnO.Fe₂O₃ or Mn₂O₄.—C.V.

High temperature furnace corrosion of type 304 alloy steel R. D. Merrick (*Corrosion*, 1960, 16, Nov., 578t-580t) The author has investigated severe corrosion occurring in 25%Cr-12%Ni steel tubes and supports in a high-temperature (1600-2100°F) furnace. The corrosion was found to be accelerated by contaminants fluxing the hot metal surfaces.

Microstructure of the scale formed on iron

and steel S. Modin (*Jernkont. Ann.*, 1960, 144, (11), 799-812).

New observations on the structure of scale and on the mechanism of scale formation during the heating of steel S. Modin and E. Tholander (*Jernkont. Ann.*, 1960, 144, (11), 813-833) Experiments are described on the scaling of electrolytic iron and C steel (rimmed and Si-killed) in air in the electric furnace, at 1000-1300°C, together with some tests in an oil-fired furnace. The mechanism of scale formation is discussed, and a hypothesis advanced which explains the formation of blisters as a function of CO pressure.

Oxidation of mild steel in high-temperature aqueous systems E. C. Potter and G. M. W. Mann (*Corros. Prev.*, 1961, 8, April, 46) Corrosion rates of unstressed mild steel in static aqueous 5-20%NaOH have been examined at 250-355°. The rate increases with concn. and temp. but decreases with time according to a parabolic relation. Under all conditions, a double partially protective layer of magnetite forms and by using the pearlite phase in the steel as a marker, it is shown that the inner layer grows at its interface with the steel; this finding is supported by the retention of surface detail and shape of the oxidized steel at the corners. During oxidation, the steel gains magnetite due to diffusion of anions through the oxide; weight is lost due to counter diffusion of Fe ions through the oxide into the aqueous environment. As a result, no appreciable stress is set up in the adherent magnetite as it forms. The same mechanism of growth probably also applies in distilled water.—C.V.

High temperature oxidation of iron-chromium binary alloys, in water vapour. Part I. A preliminary study of the mechanism of oxidation of iron-chromium binary alloys in water vapour C. T. Fujii and R. A. Meussner (*PB 161696, Final Rept. on phase I*, Sept. 1960, pp.27; *NRL Rept.* 5506; from *US Res. Rep.*, 1961, 35, Jan. 13, 91) Alloys with 5, 10, 15, 20 and 25%Cr were examined at 700°, 900° and 1100°C, and the oxides were identified by X-ray diffraction. Three phases were usually found in successive layers. The oxidation was linear at 1100° and parabolic at the lower temp.

Observations on the scale structures of mild steel strip S. Garber (*'Flat rolled products. II. Semi-finished and finished'*, Interscience Publishers, 1960, 6, 41-59) The fact that different oxide structures are found shows that scale is not a uniform material. It would appear that wüstite decomposition takes place in the scales during the slow cooling of the strip after coiling. In some regions wüstite is completely absent, the scales consisting entirely of magnetite; in others it is present as islands in a magnetite matrix. The occurrence of a pearlitic structure in decomposed wüstite is discussed. Laboratory tests have shown that the conventional scale with a layer of wüstite in contact with the metal, pickles more rapidly than the unconventional form; this latter question is being investigated. The formation of hematite at the edges and ends of coiled strip can be prevented by cooiling the strip immediately after coiling. This is advantageous in batch pickling; in the continuous process the prevention of the normal breaking pattern of the scale at the edges of a narrow strip due to the antilastic effect is more important. The necessity of examining this problem in greater detail is suggested.—C.V.

Behaviour of iron-silicon alloys between 800-1100° in carbon monoxide/carbon dioxide mixtures C. W. Tuck (*Corros. Prev.*, 1961, 8, April, 51-52) Three decarburized commercial Si-Fe alloys (1-3%Si) were oxidized using CO₂ and CO/CO₂ (1:1, 1:3) at 800-1100°. Gain in weight was measured after 15-240 min. A Si-rich scale layer was found in the 3% alloy between 800-1000° but these scales in the 1 and 1.75% alloys did not inhibit further oxidation. Above the 1000° level, this layer no longer stifled oxidation, it then being rapid and following a linear law. The oxidation rate increased with increasing O-potential. It is suggested that an increase in oxidation rate is associated with the formation of the γ -alloy at the surface as the result of the removal of Si from solution. The rate of Si-diffusion in γ -Fe is < in α -Fe and a protective Si-layer

cannot form between fayalite ($2\text{FeO} \cdot \text{SiO}_2$) and the metal. With high Si-alloys, the surface layers have a sequence $\alpha\text{-Fe}/\text{Si}/\text{fayalite}/\text{wustite}/\text{magnetite}$ while in low Si-alloys it is $\alpha\text{-Fe}/\gamma\text{-Fe}/\text{fayalite}/\text{wustite}/\text{magnetite}$.—C.v.

Corrosion testing in laboratories W. Wiederholt (*Materialprüfung*, 1961, 3, April, 20, 137-146).

Laboratory corrosion testing W. Wiederholt (*Corros. Prev.*, 1961, 8, April, 49) A general review of standard procedures.—C.v.

The accelerated corrosion testing of metals W. D. McMaster (*Corros. Prev.*, 1961, 8, April, 49).

An accelerated method of testing the resistance to corrosion of Cr electrodeposits on steel T. Biestek (*Prac. Inst. Mech. Prec.*, 1960, 8, (30), 59-79) Cr electrodeposits of various thickness ranging from 5 to 54 μ deposited from a bath containing 250 g $\text{Cr}_2\text{O}_3/\text{l}$ and 2.5 g sulphuric acid/l were exposed to the action of 5 media, NaCl, a mixture of salts, an atmosphere of industrial gases, hot distilled water and an ammonium chloride solution. The most aggressive turned out to be a solution of 20 g $(\text{NH}_4)_2\text{SO}_4$, 10 g NH_4Cl , 10 g NaCl and 10 g $(\text{NH}_4)_2\text{CO}_3$ per litre sprayed in a plexiglass chamber, since its effects became visible in 1 to 2 days, 50% of corrosion being reached after 21 to 60 days according to the ASTM method of evaluation.

Comparative corrosion tests on chromium-plated articles (*Wire*, 1961, Feb., 19-20) Based on a paper by W. Nohse, given at a conference on electroplating in 1959, a series of corrosion tests on bright-Cr plated articles is described, from which it was concluded that corrosion occurred only if the intermediate Ni layer was faulty and the condition of the parent metal did not give rise to corrosion.

Influence of water movement on corrosion. Ferrous materials G. Butler (*Corros. Techn.*, 1961, 8, Jan., 5-7).

Some factors influencing the aqueous corrosion of ferrous materials at elevated temperatures G. Butler and H. C. J. Ison (*Corros. Prev.*, 1961, 8, April, 46).

Accelerated corrosion tests from kinetic studies of rate controlling factors K. Barton (*Corros. Prev.*, 1961, 8, April, 48).

Atmospheric corrosion of steels as influenced by changes in chemical composition C. P. Larrabee and S. K. Coburn (*Corros. Prev.*, 1961, 8, April, 50) A method of testing steels is described and the types and corrosion activity of different atmospheres is compared. The results of long-time exposure tests are plotted to show the shapes of time-corrosion curves with steels of varying resistance. The effect of variation in Cr, Ni, P and Si is given and some 270 samples have been examined.

Outdoor exposure tests of electrodeposited zinc and cadmium coatings on steel T. Biestek (*Corros. Prev.*, 1961, 8, April, 50) Cd and Zn (from CN and SO_4 baths) coatings were examined in thickness of 1, 2, 4, 7, 15 and 30 microns. A visual inspection rating was used. Zn from a CN -bath showed twice the service life of Cd for the corresponding thickness as well as showing longer life than coatings from the SO_4 bath. Rates of corrosion for particular exposure location in microns per year differed for each coating; Zn-CN deposits 4-6 microns, ZnSO_4 6-9 and Cd 9-12 per year.

Coatings in tropical atmosphere exposure tests S. G. Clarke and E. E. Longhurst (*Corros. Prev.*, 1961, 8, April, 50) A general review.

The Drude-Tronstad polarimeter and its use in corrosion studies P. C. S. Hayfield (*Corros. Prev.*, 1961, 8, April, 48-49).

Potentiostatic behaviour of some Cr-Ni-Mn stainless steels I. G. Murgulescu and O. Radovici (*Corros. Prev.*, 1961, 8, April, 47) A study of three of these steels in H_2SO_4 has been carried out. Values have been obtained for Flade potential, max. current before establishment of passivity (critical current) and for the dissolution current of the passive metal film.—C.v.

Effect of nitrate solutions in producing stress-corrosion cracking in mild steel R. N. Parkins and R. Usher (*Corros. Prev.*, 1961, 8, April, 47) The effect of pH is discussed; the more acidic nitrates promote cracking most readily. Additions of oxidizing salts or acids to the solutions accelerate cracking while

hydroxides and salts forming insoluble Fe-salts retard or prevent it. Microscopical examination shows that crack propagation is preceded by an incubation period; it is considered that during this penetration of the surface oxide film takes place by acid dissolution. If the attack is to continue and the cracks propagate, an autocatalytic action is developed within the trenches; anodic stimulation is possible.—C.v.

Corrosion of iron and mild steel in nitrate solution M. Smialowski (*Corros. Prev.*, 1961, 8, April, 47).

Tin plate corrosion and technique for evaluating resistance to corrosion by acid foods G. G. Kamm and A. R. Willey (*Corros. Prev.*, 1961, 8, April, 41-42) Tin-steel potential and couple current relationships are used to describe several types of failure and the effect of corroding media on the relative potentials of tin, iron-tin alloys and steel is discussed. A theory of tin plate corrosion is presented which explains the importance of continuity of the free tin and iron-tin layers and the electrochemical nature of the base steel. The Alloy-Tin Couple (ATC) test which measures the current flowing between a large Sn-electrode and a sample of tin plate detained to the alloy layer, coupled in grapefruit juice is reviewed and a modification of this test is discussed in which corrosion rates are measured as the tin plate is detained progressively; this takes into account continuity of the free tin coating in addition to the properties measured by the standard ATC test. The findings are compared with container test pack performances.—C.v.

Electrochemical studies of pitting corrosion of passive metals U. F. Franck (*Corros. Prev.*, 1961, 8, April, 40) Pitting corrosion of passive metals (Fe, Co, Cr, Au, stainless steel, etc.) by halogen ions is studied. Under potentiostatic conditions corrosion in the form of pits occurs on the metal surface; it is characteristic and reproducible. The theory discussed is based on the fact that the current-voltage characteristic of passivable metals in non-monotonic and that a considerable resistance polarization exists within the pits; this stabilizes the heterogeneous surface structure of the pitting metal.—C.v.

Electrochemical study of austenitic stainless steel in sulphuric acid with oxidizing agents T. Ishikawa and G. Okamoto (*Corros. Prev.*, 1961, 8, April, 40) Potentiostatic and galvanostatic methods have been used together with O_2 , H_2O_2 , Co , Hg^{2+} , Fe^{3+} , Cu^{2+} , chromate, vanadate, molybdate, permanganate, persulphate, periodate and other ions. These could be classified into two groups according to their cathodic behaviour on the surface of passive stainless steel. Co^{4+} , Hg^{2+} and MnO_4^- ions were reduced at an appreciable rate on stainless steel; similar results were obtained with Pt. O_2 , H_2O_2 and $\text{S}_2\text{O}_8^{2-}$ ions were scarcely reduced on passive stainless steel although considerable reduction currents were observed on a Pt electrode. From this work, oxidants could be evaluated with respect to their ability to absorb electrons at the surface of stainless steel or they can be classified in their response to cathodic pulses and the restoration rate of potential after interrupting the pulse.

Corrosion in fused chlorides R. Littlewood and E. J. Argent (*Corros. Prev.*, 1961, 8, April, 40).

Factors which may influence the initial reaction of gases with metals M. W. Roberts (*Corros. Prev.*, 1961, 8, Apr., 39-40) The gas interaction processes taking place during the formation of the first 100 Å on a metal surface have been studied by means of metal films. The conditions are nearly ideal as the surfaces are almost free from contamination; their preparation is indicated. They are degassed, sometimes for 3 days, at low pressures and at as high a temp. as possible, depending on the vapour-pressure/temp. characteristics of the metal in question. Fe, Ni and W can be readily degassed but Cu, Li and Al are more difficult.

Influence of crystal structure on corrosion C. Edeleanu and J. G. Gibson (*Corros. Prev.*, 1961, 8, April, 39) The relationship between an etch pit and a dislocation is examined; it would appear that a correlation does not exist in every case and other factors have to be taken into consideration. One such factor is the

rupturing of the oxide film as a result of the passage of dislocations while a second is the segregation of vacancies at favoured positions such as boundaries as the result of ageing treatments. The result is the formation of voids, probably under the oxide film and it would appear probable that the attack may be associated with such voids.—C.v.

Plant inspection set up for oil field tubing (*Corrosion*, 1960, 16, Nov., 54).

Effect of metallic cations on the corrosion of iron and tin in boiling acids W. R. Buck and H. Leidheiser jun (*J. Electrochem. Soc.*, 1961, 108, March, 203-208) Boiling 0.2M citric acid and 2M HCl, in the presence of metallic cations, showed that corrosion rate was solely determined by cathodic H_2 evolution. Corrosion potential v. log corrosion rate curves obtained for Fe in the presence of various cations in 0.2M citric acid were complex; five types were found: (a) activation of the cathodic reaction produced by Ni, Rh, Ru, Ir, Pt; (b) With Sb or with bubbling O_2 through the solution activation of the anodic reaction is obtained; with (c) the anodic reaction is inhibited (Sn, Pb, In) and with (d) inhibition of the cathodic reaction is observed (Hg, Cd) and lastly with (e) both reactions are inhibited (As). Effective inhibition of the corrosion of Fe in contact with Sn in citric acid of this conc was only obtained where Sn^{2+} ions come into contact with the iron surface.—C.v.

Anodic behaviour of austenitic stainless steels and susceptibility to stress corrosion cracking S. Barnartt and D. van Rooyen (*J. Electrochem. Soc.*, 1961, 108, March, 222-229) The anodic behaviour of an ununsupervised purified stainless steel (16 Cr-20 Ni) was compared with that of a susceptible alloy (18 Cr-8 Ni) in 42% MgCl_2 . Potential-time, potential-current and potentiostatic curves were compared and it was found that dissolution from a Ni-rich surface controlled the anodic behaviour of stainless steels while potentiostatic corrosion at potentials 50-100 mv more noble than the initial immersion potential eliminated the crack initiation period, increasing the density of the cracks by two orders of magnitude in the susceptible alloy. These potentials caused rapid corrosion in the 16-20 alloy and/or deep pitting but no cracking. The potential current curves showed that propagation was accompanied by enhanced metal dissolution this being in agreement with the accepted mechanism of electrochemical cracking.—C.v.

Micro-corrosion-O-scope K. Goto (*J. Metal Finish Soc. Japan*, 1960, 11, June, 207-20; from *Japan Sci. Rev. Mech. Elect. Eng.*, 1960, 7, Aug., 177) [No abstract]

Corrosion resistant alloys. Nickel-molybdenum and cobalt-chromium base. Part I G. Koumani (*Met. Corr. Ind.*, 1960, March, 116-132) The hardness, metallography and the corrosion resistance in H_2SO_4 , HCl, and HNO_3 at various concentrations and temp. of the Adnic (Ni-Mo base) series of alloys was determined in the as-cast condition and after heat-treatment.—A.D.H.

Corrosion inhibition and molecular structure N. Hackerman and R. M. Hurd (*Corros. Prev.*, 1961, 8, April, 38) A general review.

Establishing the effect of corrosion inhibitors by potential and polarization measurements E. Uusitalo (*Corros. Prev.*, 1961, 8, April, 37) The effect of inhibitors has been studied over the range from room temp. to 180° and the action has been studied in operative equipment; the results are compared with those obtained with potential and potentiostatic polarization measurements obtained in the laboratory. Examples are given.—C.v.

Metallic Corrosion Congress: Inhibitors of metallic corrosion and the phi-scale potentials L. I. Antropov (*Corros. Prev.*, 1961, 8, April, 37-38) Abstracts from the London meeting. A new method of inhibitor study is considered; this is based on the simultaneous action of inhibitors and cathodic polarization. The ϕ -potential of an electrode is defined as the difference in potential ϵ existing under given conditions and the relative null-point, and from this the charge of the metal with respect to the solution in contact can be determined. The adsorption of particles on the surface of a

metal depends on the charge of the latter but not on the potential as given on any relative scale and the introduction of the ϕ -potential enables suggestions to be made as to the electrical properties of the particles that can be adsorbed under given conditions. Examples are given and the assumption that on the cathodes of corroding commercial metals adsorption of cations takes place is discussed. It is shown to be generally incorrect.—C.V.

A progress report on experiences in improving corrosion resistance of automobile parts J. D. Thomas, D. W. Hardesty, and C. F. Nixon (*Tech. Proc. Amer. Electrodepositors Soc.*, 1960, 90-95; discussion 239-240).

Metal spraying and painting for the protection of steel structures in polluted railway atmospheres W. J. Hair and R. Wall (*Corros. Prev.*, 1961, 8, April, 42-43) A general review.

Sprayed metal coatings for immersed conditions W. E. Ballard and R. E. Mansford (*Corros. Prev.*, 1961, 8, April, 42).

New cathodic protection technique based on adjustment of quantity of electricity to potential B. Hueze (*Corros. Prev.*, 1961, 8, April, 41).

Evaluation of electrolytic process for reduction of corrosion in steel sea water piping J. A. H. Carson (*Corros. Prev.*, 1961, 8, April, 41).

Use of anodic passivation for corrosion mitigation of iron and alloy steels D. A. Shock, J. D. Sudbury, and O. L. Riggs jun. (*Corros. Prev.*, 1961, 8, April, 40-41) Early work showed that the durability of the passive layers was sufficient to make anodic protection practical and an electronic control system was devised which would accept large current demands while maintaining the steel at a preset potential. Pilot and plant tests have shown that this could be applied to acid storage tanks and vessels used in sulphonation and neutralization. Examples are given and the limitations associated with halogen concn. are discussed together with tests used in stress-corrosion cracking.—C.V.

The zero charge potential of metals in relation to the inhibition of corrosion D. M. Brasher (*Corros. Prev.*, 1961, 8, April, 38) The suggestion is advanced that inhibition in acid and neutral solutions is initiated by adsorption and that the potential of the metal surface, in relation to its zero charge potential, determines whether adsorption (and hence inhibition) occurs in both environments. This is discussed more fully. The growth of oxide film takes place on the passivated surface and therefore occurs only when passivation has been established; this view is examined in relation to other work which has been carried out and other data in the literature are quoted.

Design for prevention of pipe line corrosion based on survey of ground potential distribution S. Fukuta, S. Kondo, N. Usami, and S. Sekimoto (*Corrosion*, 1961, 17, Jan., 50t-52t).

Methods and experience in underground cathodic protection O. Henderson, L. H. West, and P. P. Skule (*Corrosion*, 1961, 17, Jan., 45t-49t).—G.F.

Deck-side plating job solves sub's galvanic corrosion problem Metachemical Associates Inc. (*Corrosion*, 1961, 17, Jan., 25).

Automatic control of a platinum anode cathodic protection system R. C. Francis and L. S. Birnbaum (*Corrosion*, 1961, 17, Jan., 20-22) Operational tests of an automatically controlled impressed current cathodic protection system on a US Navy destroyer have shown that such a system effectively controls corrosion. The system makes use of Pt-Pd alloy anodes, and Ag-AgCl reference electrodes.—G.F.

Unusual problems encountered in cathodic protection of Miami Seadium E. J. Tilton jun. (*Corrosion*, 1961, 17, Jan., 16-18).

Pipeline cathodic protection economics F. A. Therrell jun. (*Corrosion*, 1961, 17, Jan., 12-13).

Combined cathodic protection and cleaning for heat exchangers M. J. Olive (*Corrosion*, 1961, 17, Jan., 9-11) The author describes the combined cathodic protection and cleaning of heat exchangers at Arkansas Fuel Oil Corp.

Impressed current anodes for cathodic protection W. P. Noser (*Corrosion*, 1960, 16, Dec., 587t-592t) The author reviews the develop-

ment and use of impressed current anodes for cathodic protection of underground structures, and presents data for calculating anode resistance to earth. Recommendations for various soil conditions are given.—G.F.

New developments in the mitigation of corrosion in the utility field E. H. Thalmann (*Corrosion*, 1960, 16, Nov., 543t-552t).

ANALYSIS

On the differential thermal analysis of corrosive substances F. Kupka (*Silikáty*, 1960, 4, (2), 176-179) [In Czech] DTA equipment utilizing a vertical furnace is described. The corrosive substance to be studied is separated by a layer of alumina powder from the thermoelements. It is shown that with the design used the sensitivity of the apparatus is adequate to register effects even due to such 'weak' transformations as that of the polymorphic change of quartz.—P.F.

Sampling of liquid metals T. B. King (*ISI Special Report* (68), 1960, 3-18).

Investigation of the completeness of recovery of the sulphur content of metallurgical products in various combustion methods D. Blazek-Ditges (*Arch. Eisenh.*, 1960, 31, Dec., 717-722) The sources of error in the Holthaus method for the determination of the S content of iron and steel are discussed, and it is shown that the method according to Pontot and Boulin gives complete S recovery. The Schmidts and Baasch apparatus is discussed, and finally a simplified suction method for determining S in structural and high-speed steels, ores, slags, and pig and cast iron is described.

International Committee for the analysis of gases and metals A. Høy (*Tek. Uke.*, 1961, 108, Jan. 26, 87-89) The composition of this committee, formed in 1957, is given, and its work summarized, with particular reference to the determination of H_2 in steel, and the preparation of a standard for the sampling of liquid steel for H_2 analysis.

An assessment of carrier-gas methods for the determination of gases in metals with particular reference to steel C. E. A. Shanahan (*ISI Special Report* (68), 1960, 75-92) The advantages of using this technique for the determination of O_2 , H_2 , and N_2 in metals instead of the vacuum extraction procedures are discussed.

Determination of hydrogen in cast iron J. V. Dawson and L. W. L. Smith (*ISI Special Report* (68), 1960, 219-228) The hot extraction process at 1070° using chill-cast samples is employed the gases being pumped from the furnace into a known connecting volume which is divided into two sections by a heated Pd thimble. The partial pressure of H_2 is measured in one by McLeod and Pirani gauges and a continuous record of gas evolution results. Various sampling techniques are considered and the loss of H_2 during storage is discussed.

The determination of hydrogen in metals R. Eborall (*ISI Special Report* (68), 1960, 192-218) A review.

Detection and control of chemisorbed hydrogen during electrolysis S. C. Lawrence jun. (*Tech. Proc. Amer. Electroplaters' Soc.*, 1960, 135-137; discussion 243).

An improved carrier-gas technique for the determination of hydrogen in steel F. R. Coe and N. Jenkins (*ISI Special Report* (68), 1960, 229-235) With the thermal conductivity cell very small amounts of H_2 can be detected with precision in a stream of A and a chart recorder can follow the evolution. The Katharometer possesses high sensitivity; 5 g samples giving only 0.05 ml H_2 (NTP) at the 1 ml/100 g level can be used the precision being ± 0.002 ml H_2 (NTP). Samples are introduced into the furnace by a simple air lock and the determination is completed in 30 min. Errors are avoided by using a drying train and high purity A.

The determination of oxygen in metals W. T. Elwell (*ISI Special Report* (68), 1960, 19-42) The methods used for determining O in metals are, vacuum fusion, inert gas fusion, chemical, and physical. These are discussed (129 refs).

The determination of oxygen and nitrogen in iron and steel by an isotope-dilution method M. L. Pearce and C. R. Masson (*ISI Special Report* (68), 1960, 121-132) The results ob-

tained by this method for both gases are significantly higher than those found by vacuum-fusion.

Determination of nitrogen in metals J. D. Hobson (*ISI Special Report* (68), 151-182) Volumetric methods are discussed and the essential points are tabulated. The identification of nitrides from X-ray crystallographic data is presented in a table, likewise the salient points relating to vacuum fusion methods are reviewed (165 refs).—C.V.

Determination of nitrides in metals H. F. Beeghly (*ISI Special Report* (68), 1960, 183-191) All the nitrides quantitatively recovered by other methods are also found in the residues obtained by the use of the ester-halogen reagents. Nitrides of Nb, Ti, and V have been separated by solution of the alloy in aqueous acid. The preferential method depends on the ease with which the matrix dissolved in the ester-halogen or acid; the nitride is subsequently recovered by filtration. Al- and Si-nitride (from steels low in Si) and ZrN are decomposed by prolonged contact with aqueous acids or alkalis. In isolated mixtures of the three, AlN is decomposed by an alkaline wash and the other two are relatively unattacked. Thermal treatment alters the amount of Si-nitride recoverable from high Si-steels and when ester-halogen reagents are used Si- and Al-N are similarly affected. When Al is present with Si, V, and Ti, the major portion of the N is usually combined with Al. The presence of S or C may alter the availability of the elements to form nitrides.—C.V.

Determination of cobalt in heat-resistant alloys H. Kirtchik and F. H. Sweringen (*Analyst*, 1961, 86, March, 188-195) A method for determination of Co is presented in which its specific precipitation by a combination of phenylthiohydantoic and thioglycolic acids is accompanied by trace amounts of iron and nickel, thus offering no hindrance to subsequent direct potentiometric titration with potassium ferricyanide solution in the presence of ethylenediamine.

Determination of zirconium with benzoyl-phenylhydroxylamine D. E. Ryan (*Can. J. Chem.*, 1960, 38, Dec., 2488-2492) Zr is completely precipitated by this reagent from 0.5N acid solutions and the complex formed in H_2SO_4 solutions has a constant composition $Zr(C_{13}H_{10}O_2N)_4$; this is used for the direct weighing of Zr, the factor being 0.097. The reaction is sensitive, 1 ppm Zr being detectable, and a quantitative determination of 0.2 mg is possible; Th and the rare earths do not interfere.—C.V.

Indirect volumetric determination of uranium J. Lovasi (*Koh. Lapok*, 1961, 94, Feb., 86-88)

Photometric determination of As in iron ores E. Wrzesinska (*Prac. Inst. Hut.*, 1960, 12, (6), 289-293) The method proposed is a modification of that for determination of As in Cu by Steele and England (*Analyst*, 1957, 82, 595), to replace both the distillation and the volumetric methods. Reproducibility is 0.002% for contents up to 0.1%As and 0.004% for higher contents.

Determination of boron in steels B. Kysil and J. Vobora (*Coll. Czech. Chem. Comm.*, 1959, 24, Dec., 3893-3902) [In German] A colorimetric method with quinalizarin, or for contents > 0.2% alkalimetric titration using potentiometric pH observation are described (16 refs).

Direct absorptiometric determination of copper in steel and cast iron with 2,2'-bi-quinolyl C. E. A. Shanahan and R. H. Jenkins (*Analyst*, 1961, 86, March, 166-171) A method is presented whereby the copper 2,2'-bi-quinolyl complex is formed in an aqueous solution containing NN-dimethylformamide. It is very suitable for rapid routine work and its overall accuracy is shown by results for plain-carbon and alloy steels, and for cast irons.

Photometric determination of traces of lead in iron and steel S. Meyer and O. G. Koch (*Arch. Eisenh.*, 1960, 31, Dec., 711-715) The method, suitable for determining 0.0001-0.05%Pb, consists in separating the iron by extraction with diethyl or diisopropyl ether, shaking the Pb soln. with diethione in $CHCl_3$, determining photometrically. The mean relative error is $\pm 5\%$, and time of analysis 4-6 h (41 refs).



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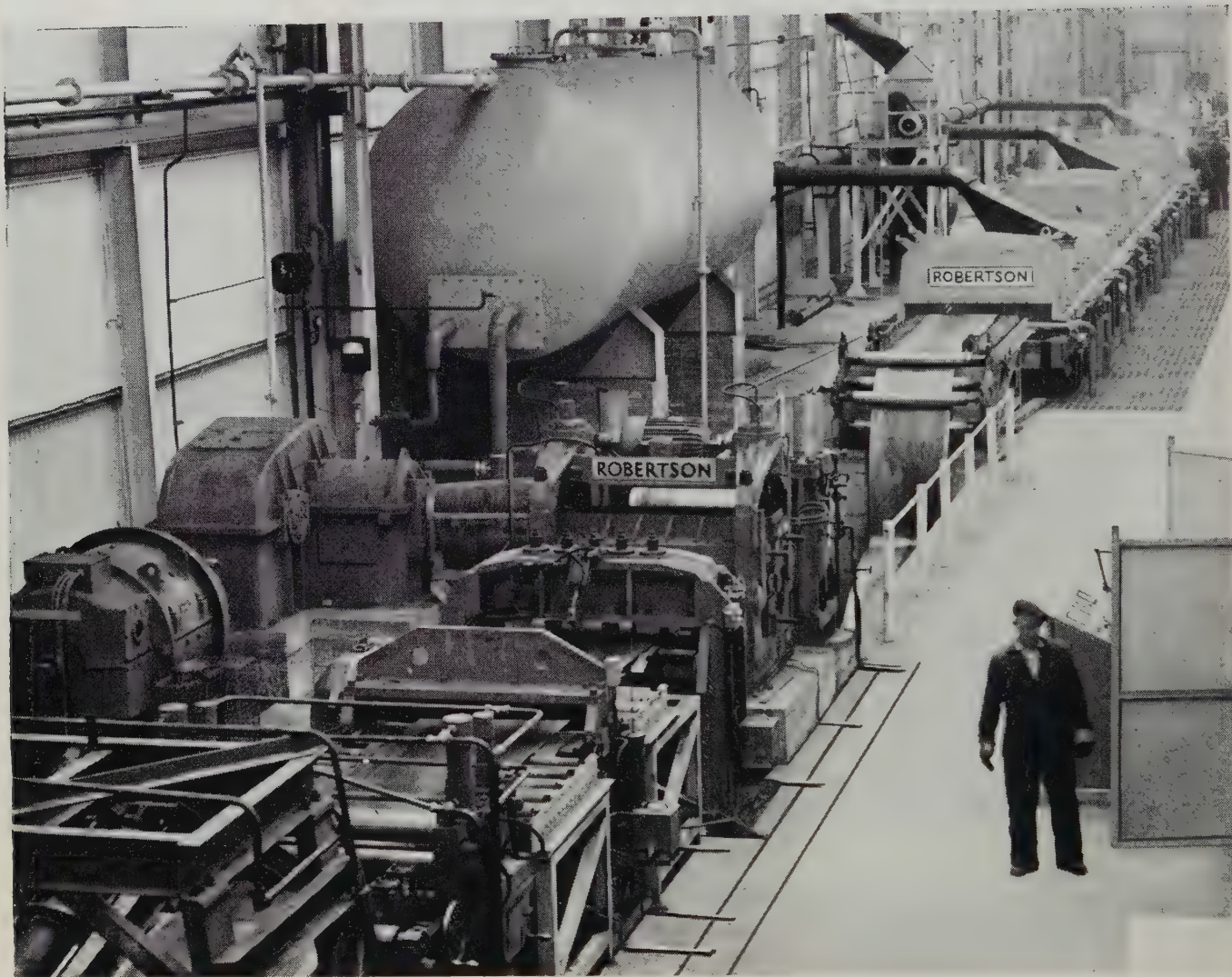
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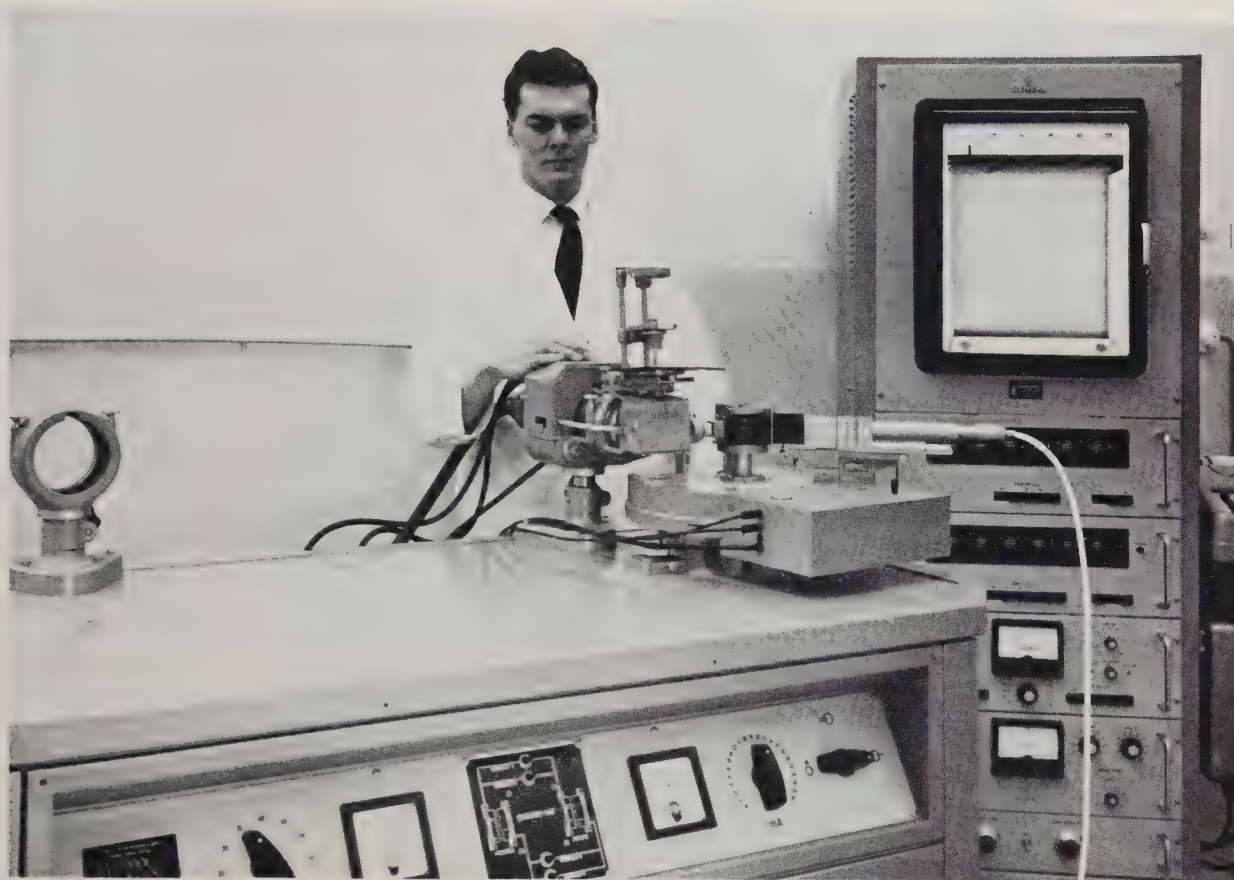


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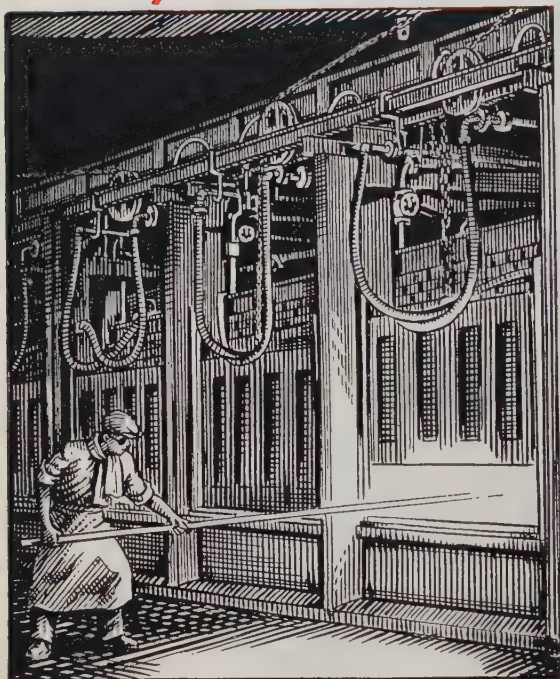
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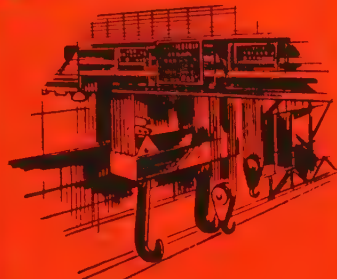
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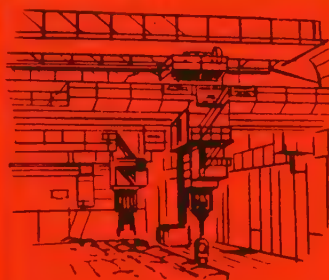
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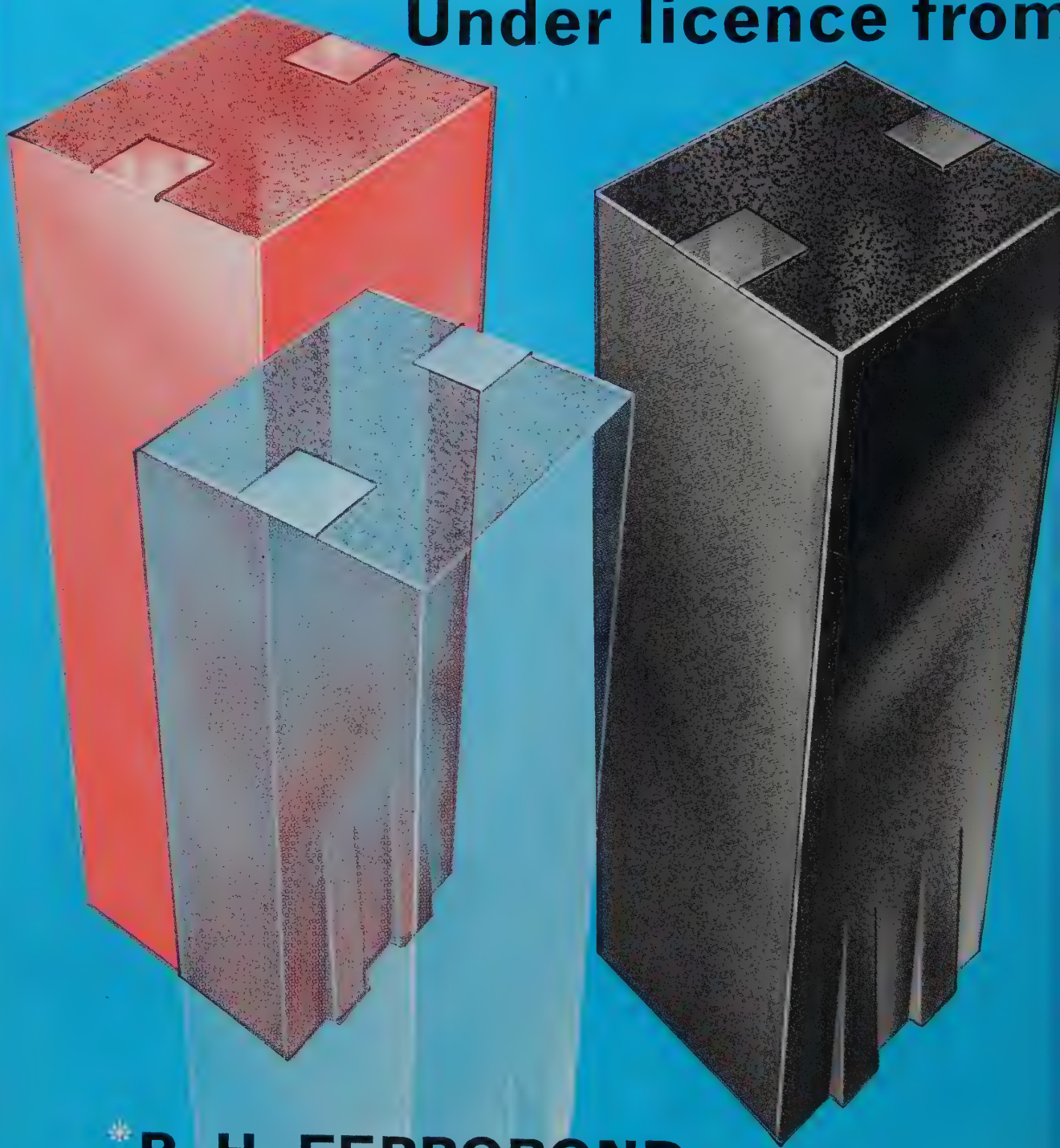
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190 Tons	12" Rib 9" Valley	250 Heats 75 Days	47,500 Tons	26	2.2%	12.6%	2
190 Tons	All 12"	405 Heats 130 Days	77,000 Tons	25	62%	67%	2
200 Tons	15" Rib 12" Valley	488 Heats 196 Days	100,000 Tons	21	2.8%	6.6%	NONE
345 Tons	15" Rib 12" Valley	453 Heats 170 Days	157,000 Tons	38.5	10.4%	19.0%	2
400 Tons	15" Rib 12" Valley	298 Heats 186 Days	120,000 Tons	27	NIL	NIL	2

This chart shows comparative performance records in North America of six typical open hearth roofs. In each case the roof was constructed half-and-half of Lavino Ferrobond CMX 3" x 3" Roof Keys and Internally Plated 4½" x 3" Roof Keys.

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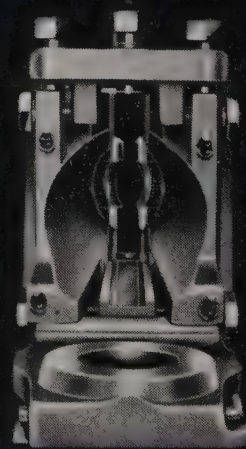
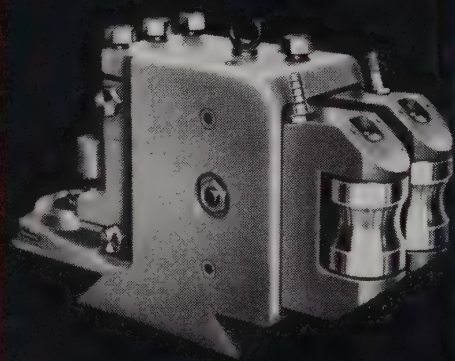
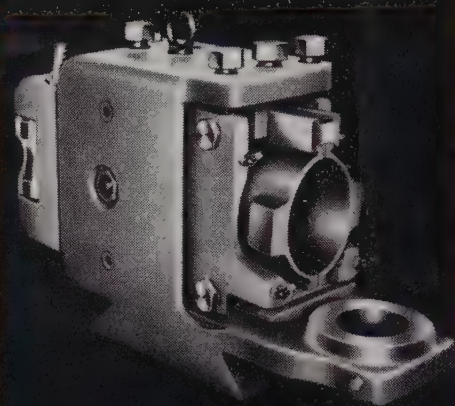
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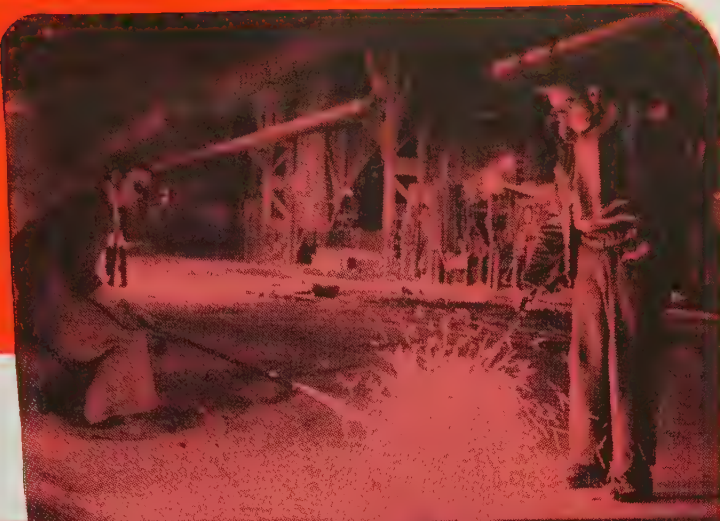
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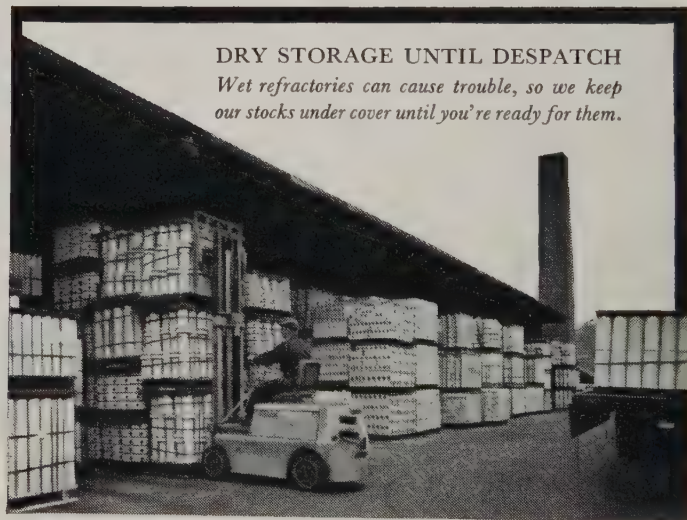
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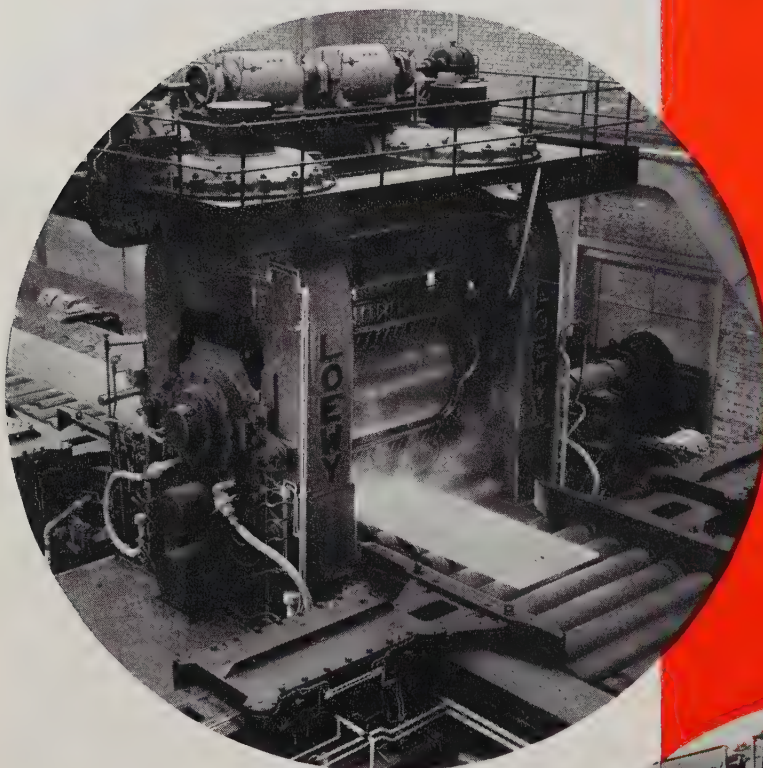
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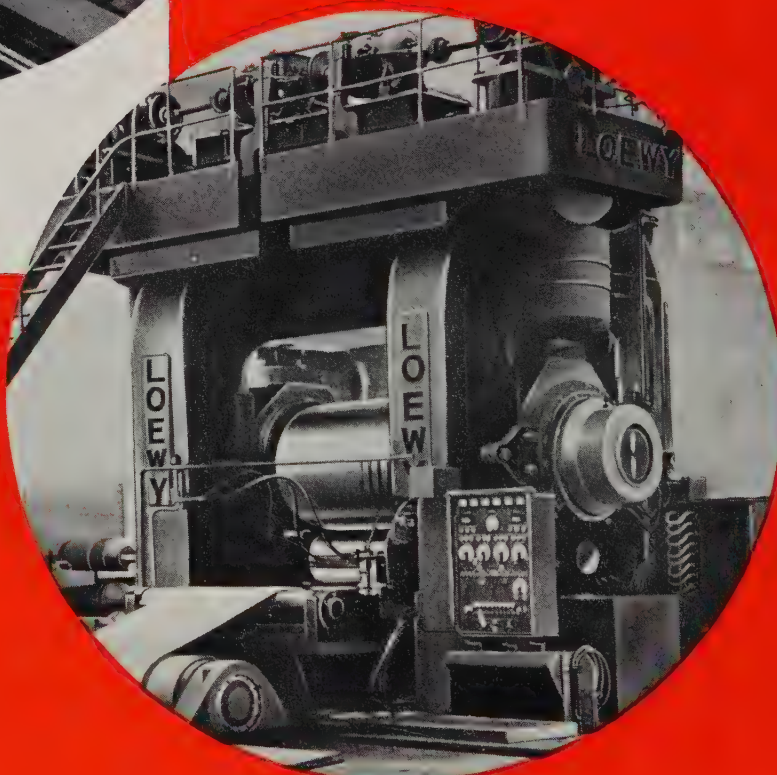
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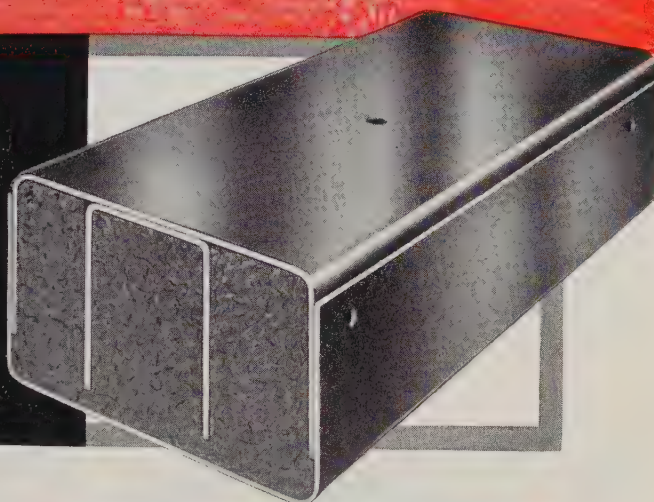
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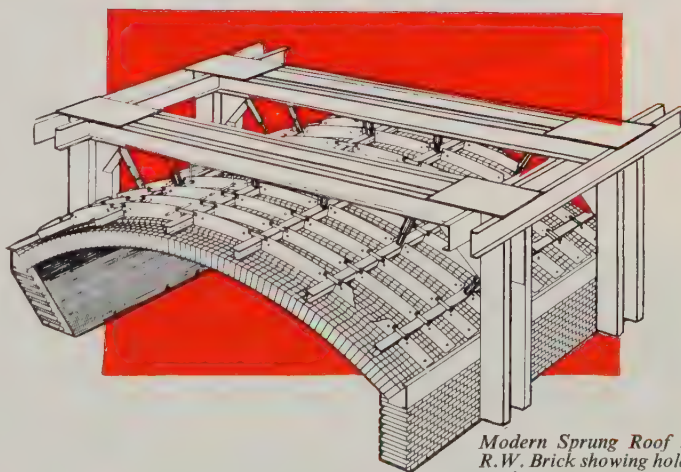
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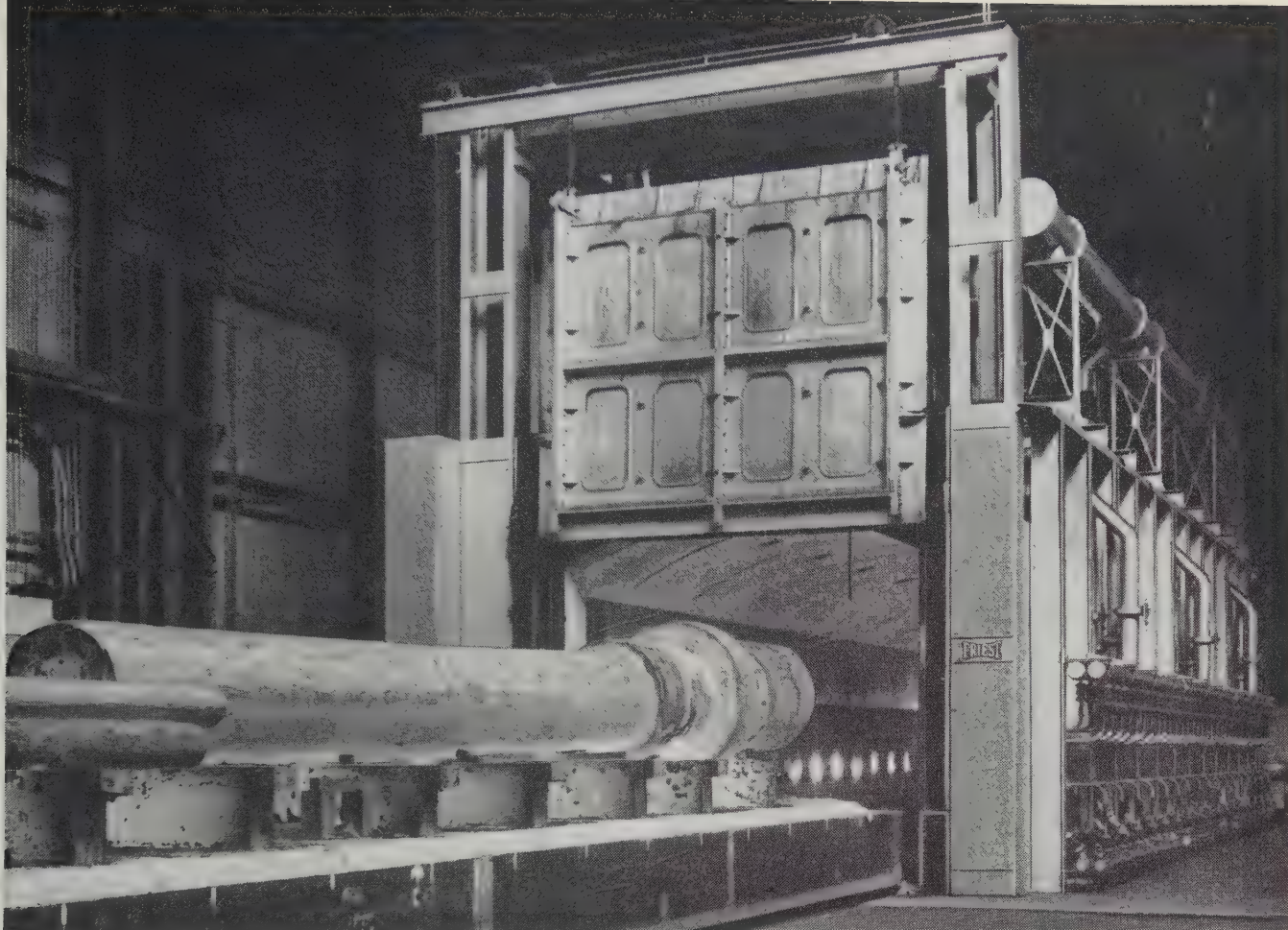
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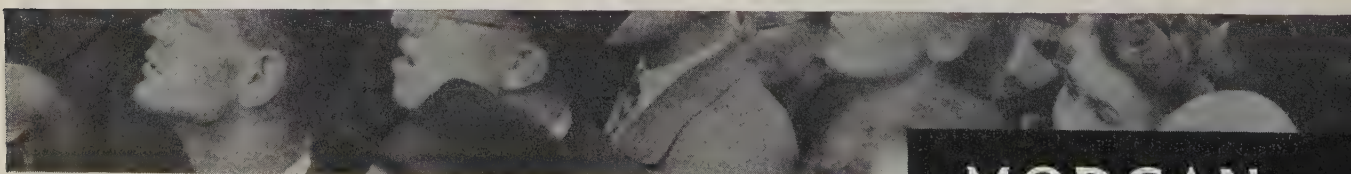
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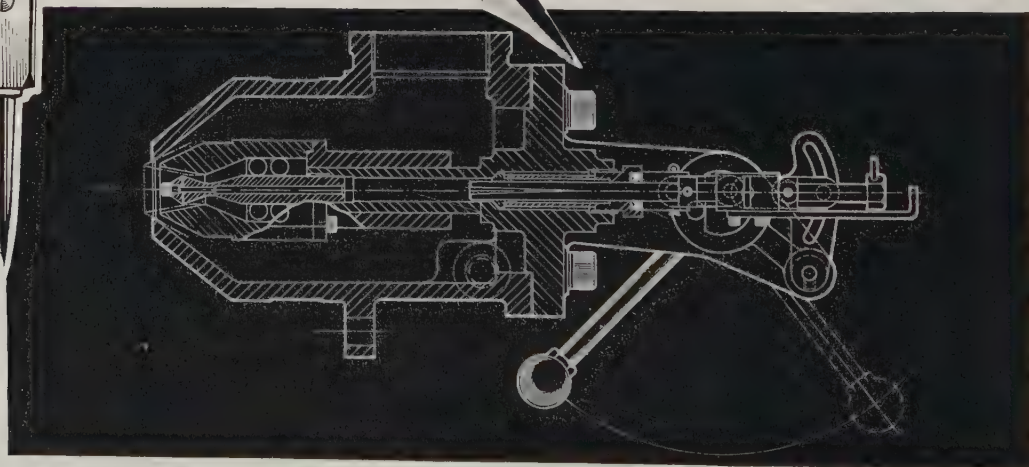
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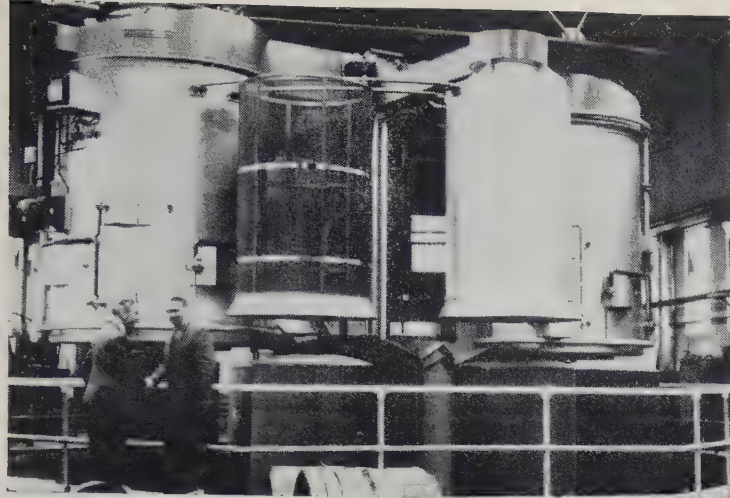
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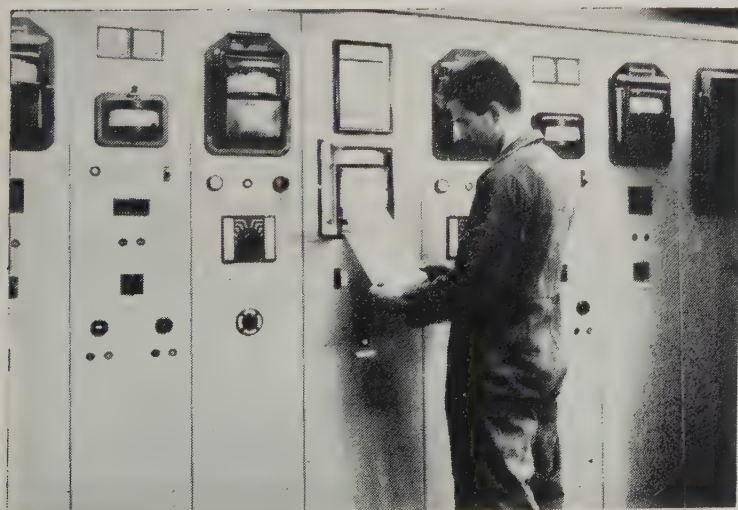
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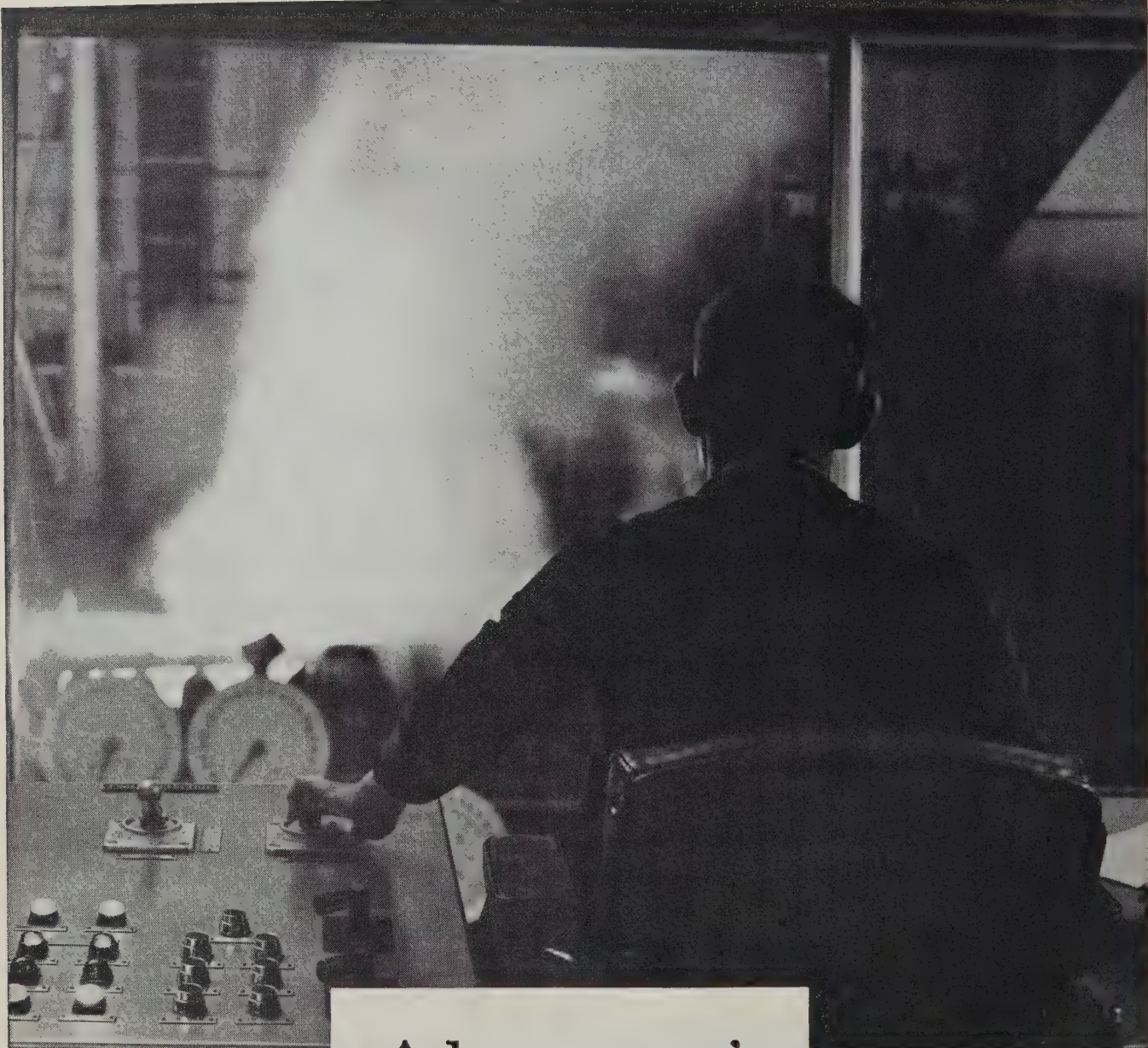
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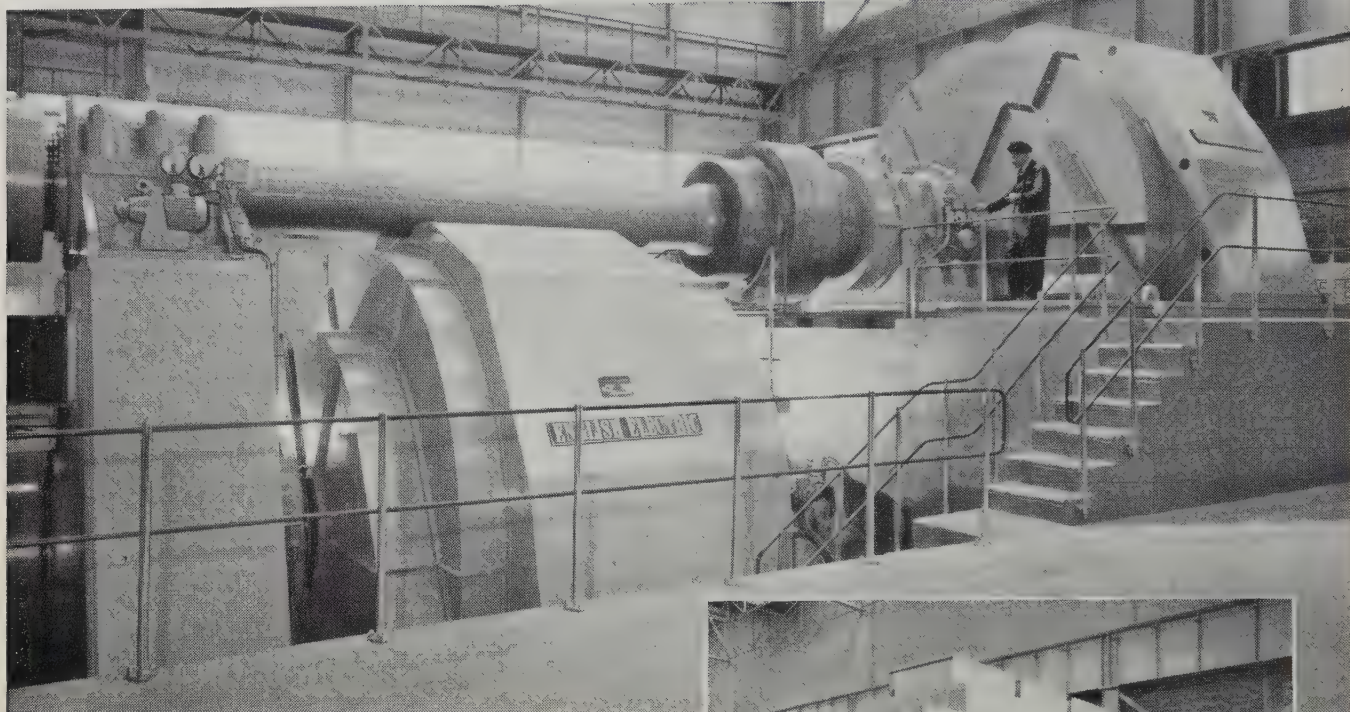
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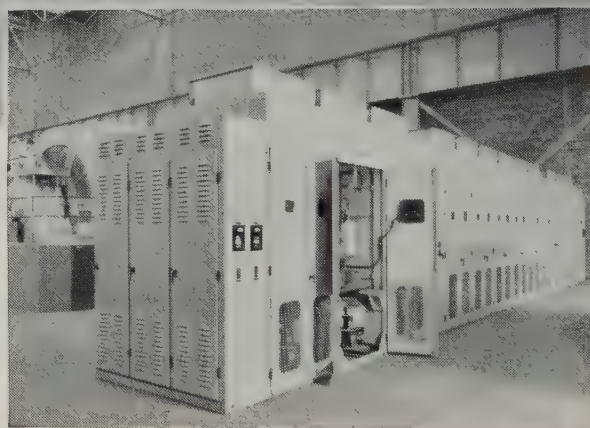
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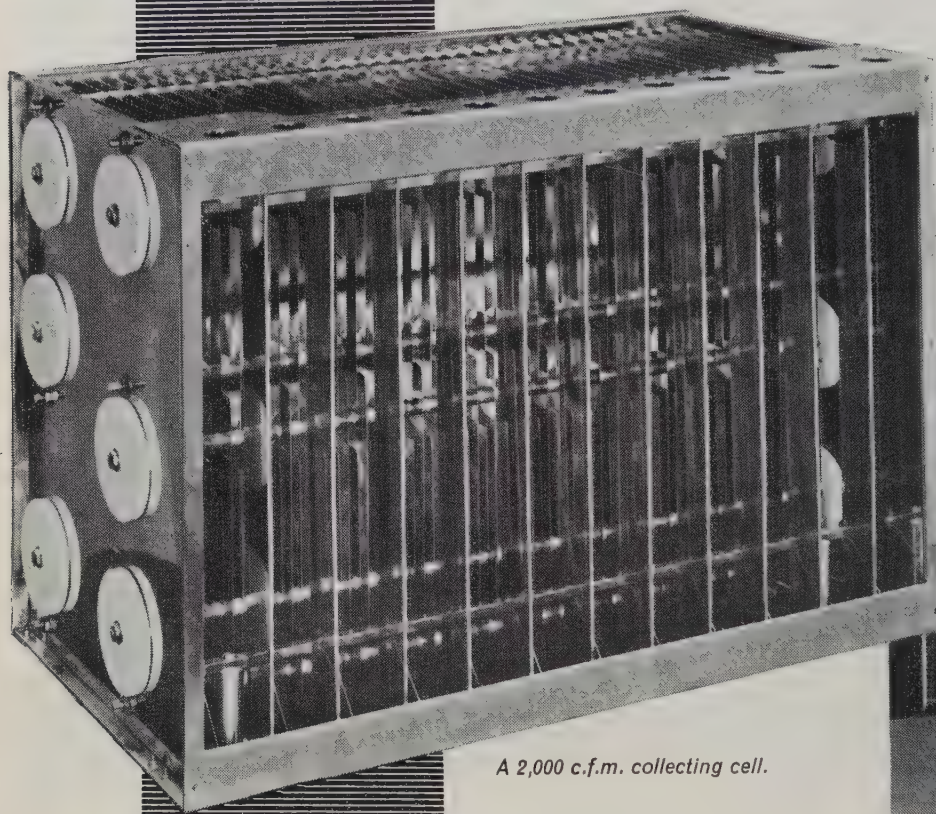
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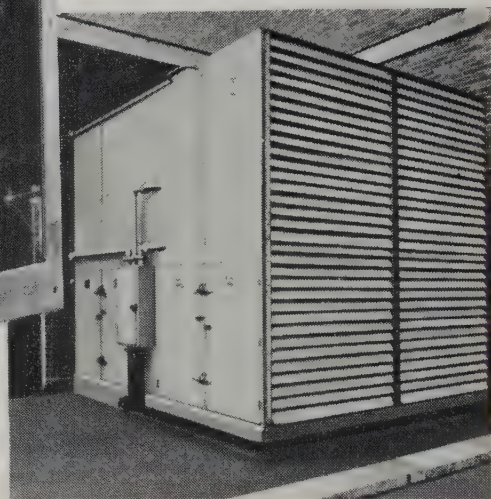
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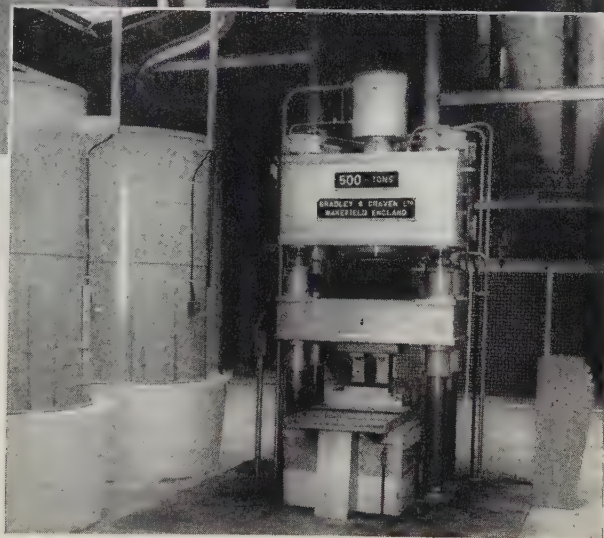


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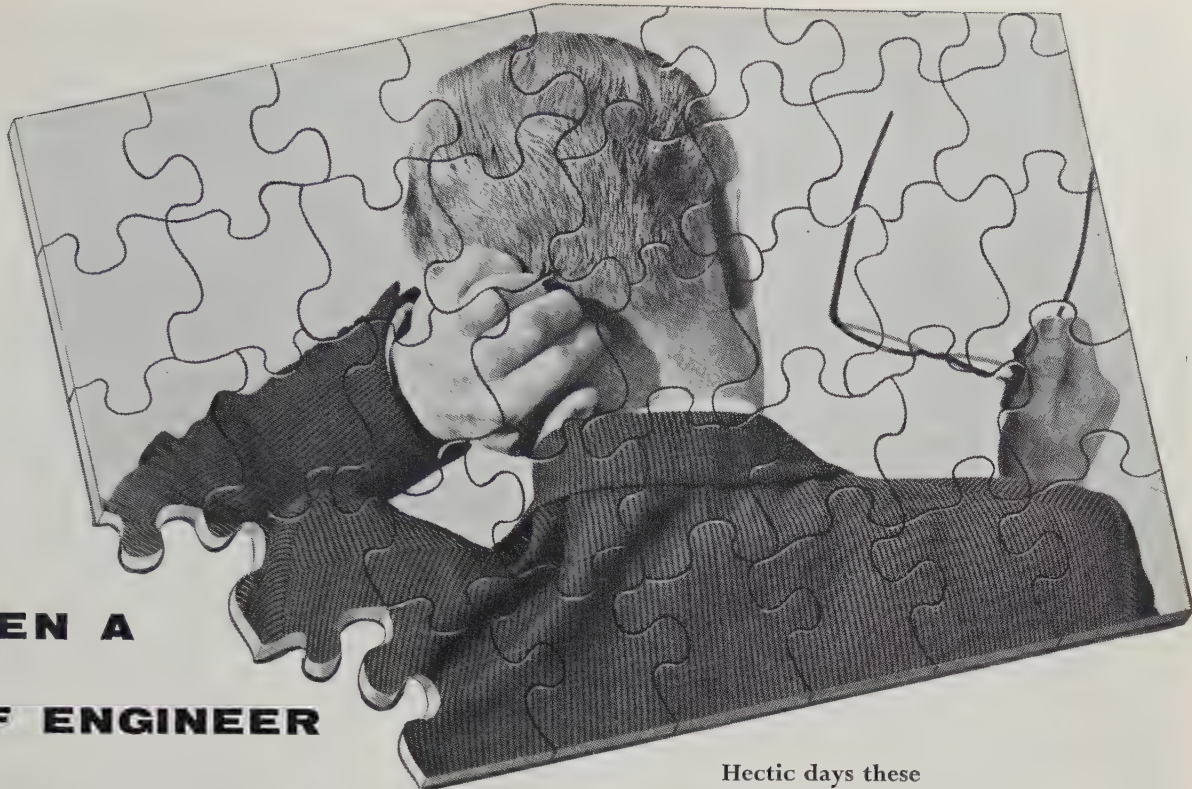
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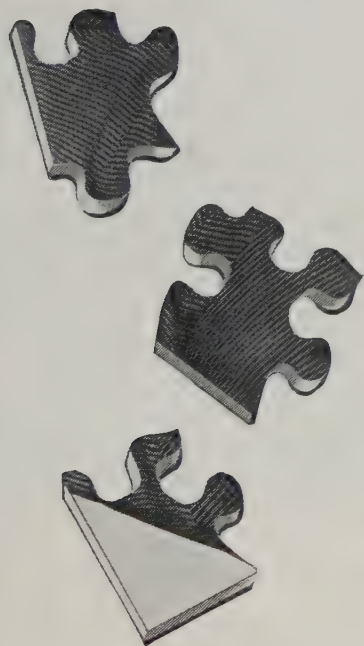


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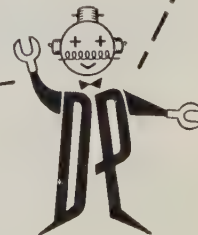
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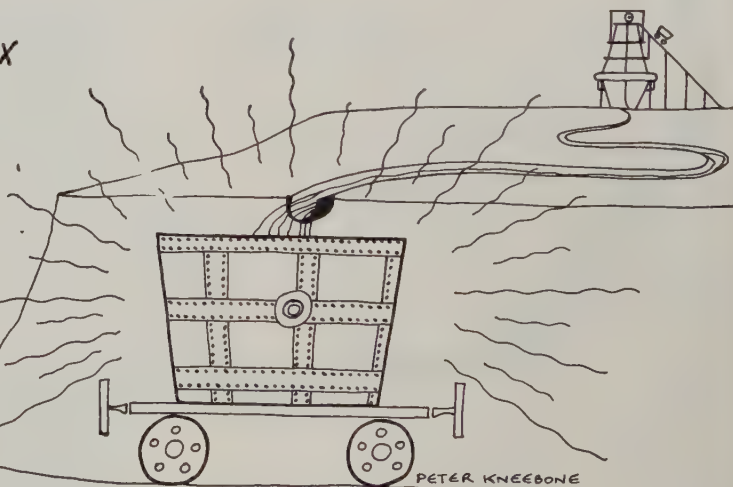
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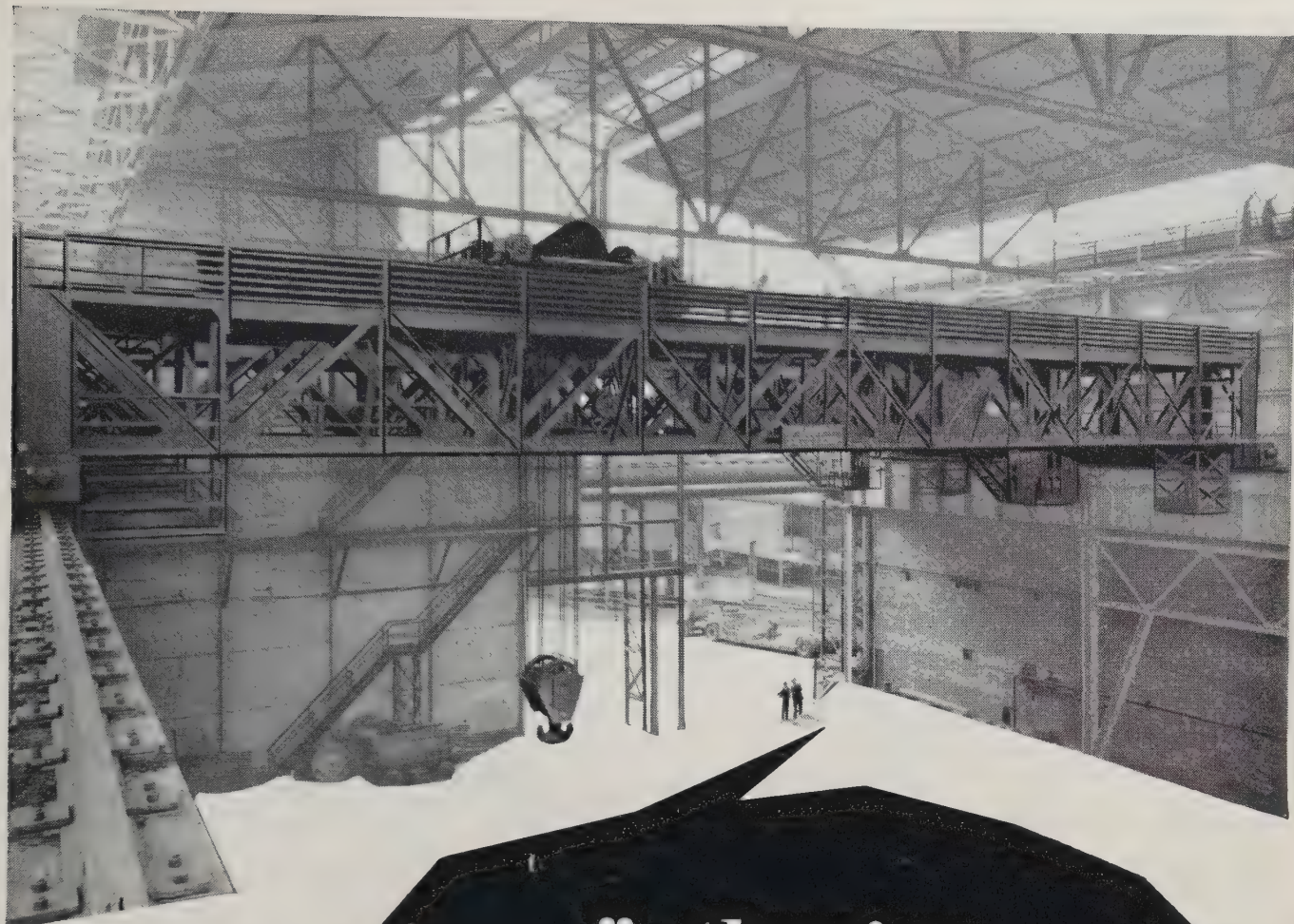
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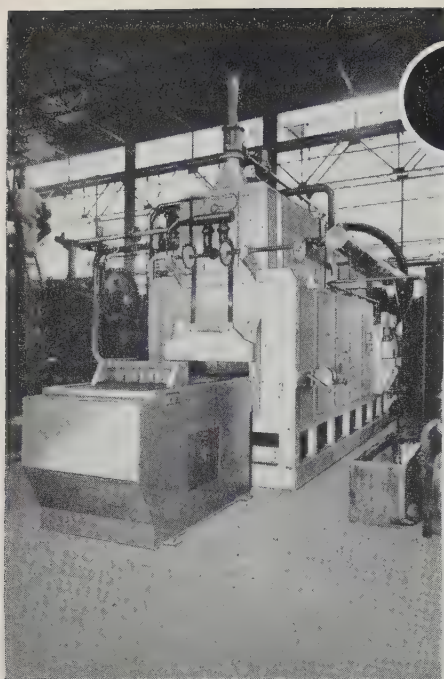
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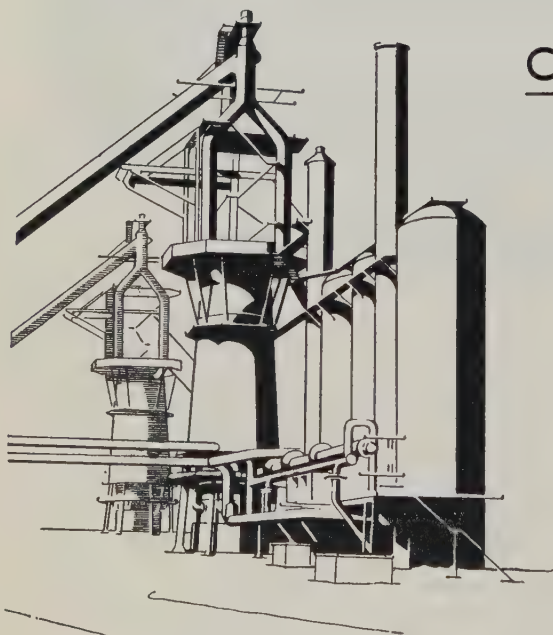


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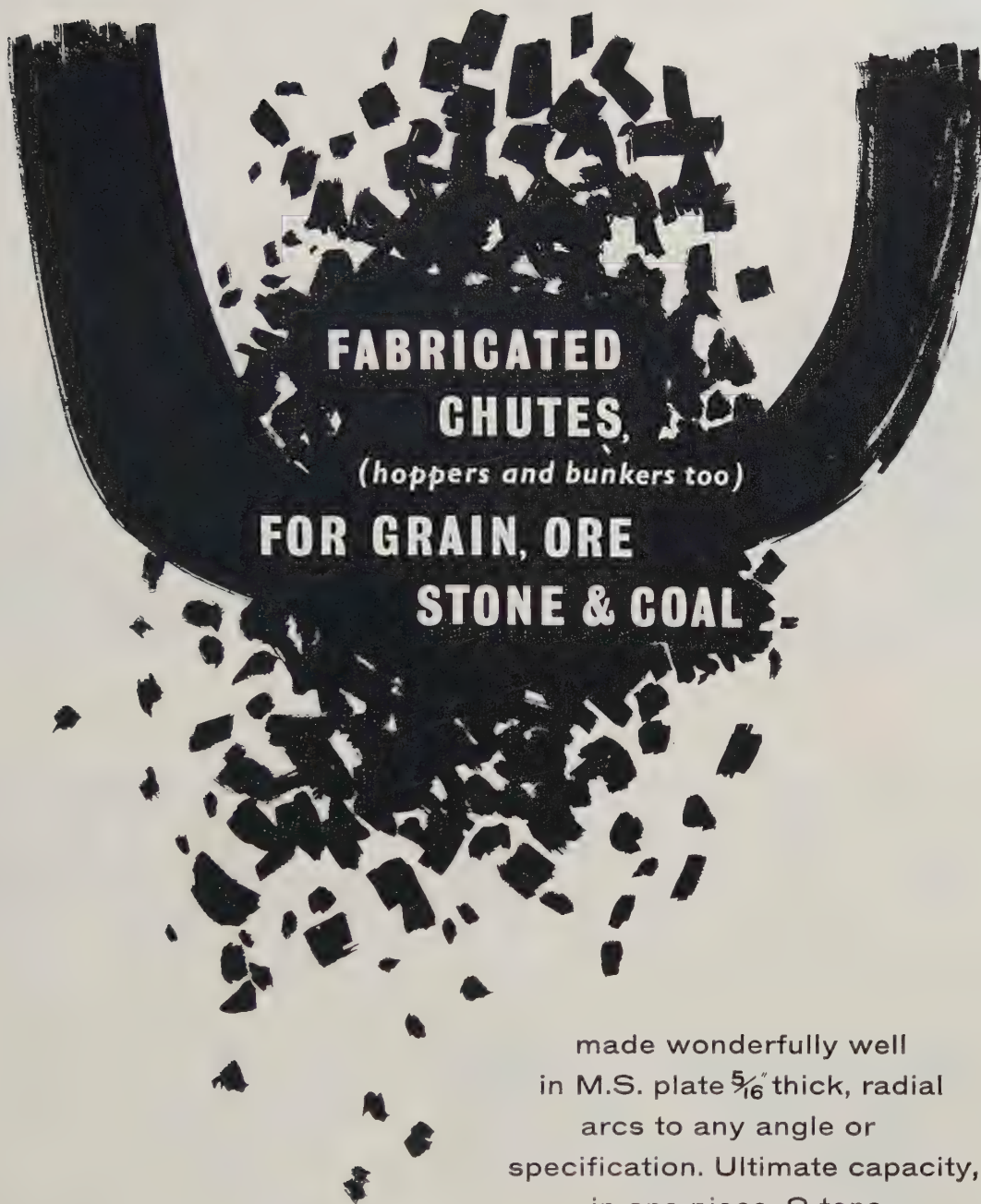
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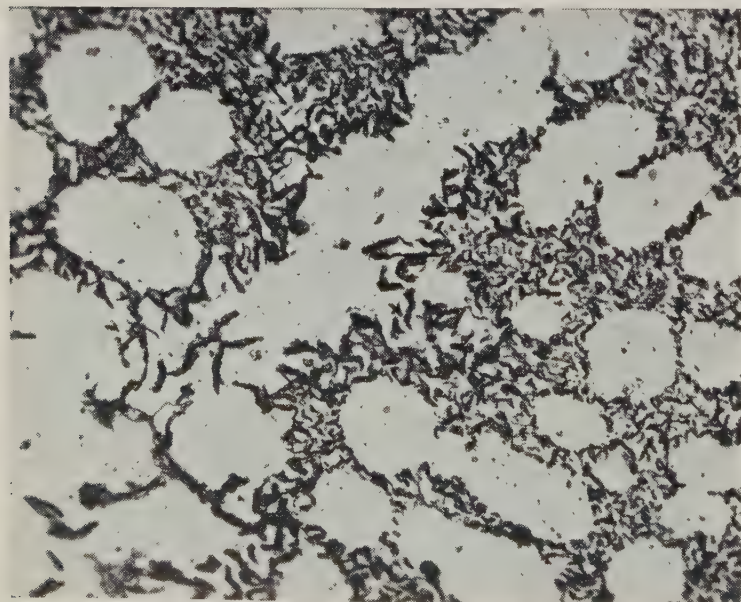
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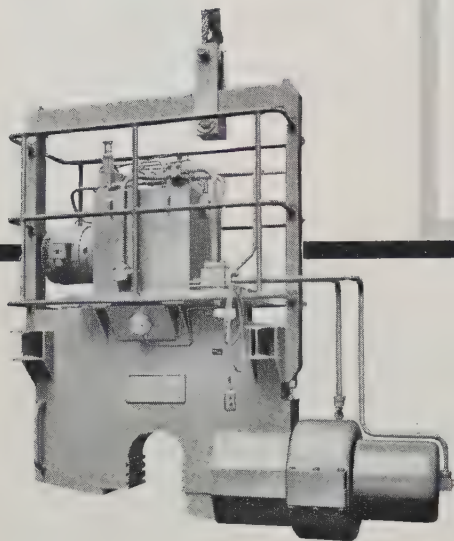
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SCHMIDT, T.
WUNNING, J.

. 621.785.34.062.3

The possible exchange of matter between furnace atmosphere and work in routine annealing of cold worked steels in protective atmospheres.

(*Stahl Eisen*, 1961, 81, March 16, 361-366).

From equilibrium diagrams for oxygen- and carbon-involving reactions the possibility of certain reactions taking place during the annealing of steel in protective atmospheres is discussed. Tests on bell-type and continuous furnaces showed that large deviations from equilibrium conditions in fact occur. The actual phenomena such as oxidation and decarburization are discussed. It is for this reason that more recently protective atmospheres have been used which do not contain reactive components but are inert towards the work. - T.G.



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they are printed in the *Journal* under subject headings. This will enable a simplified continuous subject index to be kept with no extra trouble.

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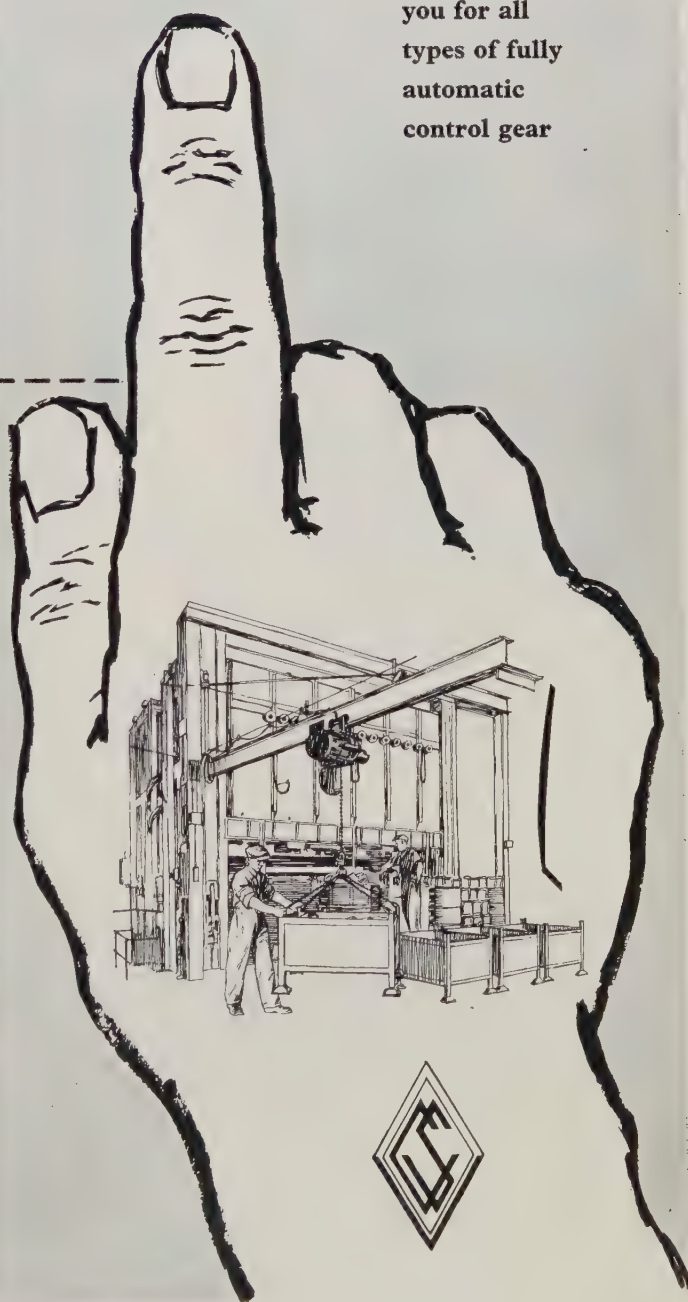


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A symposium on steels for reactor pressure circuits, organized by The Iron and Steel Institute for the British Nuclear Energy Conference, took place in London at the end of last year. Sir Leonard Owen's introductory address, the 26 papers which were delivered, and the six related discussions, have now been published by the Institute as its Special Report 69

Steels for reactor pressure circuits

The papers and discussions are in five general groups: high-temperature properties, corrosion, fabrication aspects, irradiation effects, and steels for future reactors. The report ends with a general discussion.

In octavo format, with 587 pages of text and extensive illustrations in line and tone, the report costs 65s. (postage included) and is available from the Secretary of The Iron and Steel Institute, 4 Grosvenor Gardens, London SW1.

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